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SSALTO

ALGORITHM DEFINITION, ACCURACY AND SPECIFICATION VOLUME 12: CMA/DORIS IONOSPHERIC PROCESSING

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ABBREVIATIONS

Sigle	Definition
ADA	Algorithm Definition and Accuracy
ADx	Applicable Document x
CLS	Collecte Localisation Satellites
CMA	Centre Multi-missions Altimètre
CNES	Centre National d'Etudes Spatiales
DAD	Dynamic Auxiliary Data
DIP	Magnetic Inclination
IGRF	International Geomagnetic Reference Field
ITRF	International Terrestrial Reference Frame
JPL	Jet Propulsion Laboratory
LS	Least Square
RDx	Reference Document x
SAD	Static Auxiliary Data
SSALTO	Segment Sol Altimétrie et Orbitographie
SWT	Science Working Team
TBC	To Be Confirmed
TBD	To Be Defined
TEC	Total Electronic Content
UTC	Universal Time Coordinate

APPLICABLE AND REFERENCE DOCUMENTS

Reference	Document title	
TP2-SB-J0-459-CNES	AD1	JASON-1 Products Description
TP2-SB-J0-102-CNES	AD2	JASON-1 Science and Operational Requirements
SMM-ST-M2-EA-10658-CN	AD3	CMA Requirements Specification
SMM-ST-M1-EA-20077-CN	AD4	DORIS Level 1.0 data product
SMM-ST-M2-EA-11010-CN	AD5	Algorithms Definition, Accuracy and Specification Volume 9: CMA Mechanisms
SMM-IF-M2-EA-20207-CN	AD6	SSALTO Internal Interfaces Specifications : CMA (CAL and TEC products)
SMM-SP-M2-EA-32056-CLS	RD1	CMA Production: Specification of the Data Management Algorithms for the Doris ionospheric processing
SMM-DD-M2-EA-32062-CLS	RD2	CMA Production: Internal interfaces for the Doris Ionospheric processing
SMM-SP-M2-EA-32061-CLS	RD3	Processing steps for the Doris Ionospheric processing
SMM-NT-M231-EA-786-CLS	RD4	Traitement ionosphérique des données Doris
CM-ST-6136-393-CLS	RD5	Spécification des algorithmes de traitement ionosphérique du niveau 1-0 au niveau 1-1
CM-ST-6136-394-CLS	RD6	Spécification des algorithmes de traitement ionosphérique du niveau 1-4 au niveau 1-5
CM-ST-6136-395-CLS	RD7	Spécification des algorithmes de traitement ionosphérique du niveau 1-5 au niveau 2-0
	RD8	NAG Fortran Library Manual – Mark 18

TBC AND TBD LIST

TBC/TBD	Section	Brief description
/	/REF	/

CONTENTS

1. INTRODUCTION

This document is aimed at defining and specifying the main functions of the nominal Ionospheric processing of the DORIS data. Regarding the JASON-1 mission, the highest level requirements placed by the JASON Science Working Team upon the JASON project to meet the scientific and operational objectives of the mission are listed in AD2, and the requirements aimed at defining the CMA facility inside the SSALTO system are established in AD3.

The IONO processing starts from the DORIS level 1.0 product (see AD4), and generates the DORIS-derived TEC maps, the content of which is given in AD6.

As previously mentioned, this document deals with both the definition of the IONO processing and the specification of its main functions.

Definition of the IONO processing

The definition of the IONO processing consists of the identification and the description of its main functions. It will provide the reader with an overview of the processing and a global understanding of the algorithms.

Specifications of the IONO processing

Regarding the specifications of the IONO processing, two kinds of algorithms are distinguished:

- The “scientific” algorithms, which represent the core of the processing
- The other algorithms, which will be called the “data management” algorithms, ensuring functions such as:
  - To get the input data
  - To prepare the data to be processed (for example to select the orbit data set requested to compute the location of each altimeter measurement)
  - To perform unit conversions or changes in reference systems
  - To perform general checks (relevant for example to the presence of input files, to the data conformity or to the compatibility of input data with the data set to be processed)
  - To build the output product(s)
  - To manage the processing

The scientific algorithms are specified in this document and in AD5 for the mechanisms, which represent the functions common to several algorithms or the functions frequently requested within an algorithm. The data management algorithms, which strongly depend on the format of the input and output data, are specified in RD1 (and AD5 for the corresponding mechanisms, if any). The complete set of specifications (to be associated with the corresponding interfaces documents) is intended for the team in charge of the software development.

Conventions

The IONO processing is represented in this document as a linear set of functions which are aimed at building the DORIS-derived TEC maps from a set of level 1.0 parameters. This representation has been chosen for historical reasons in order to ease the understanding of the overall processing, but it does not anticipate the organization or the sequencing of the algorithms within the CMA processor.

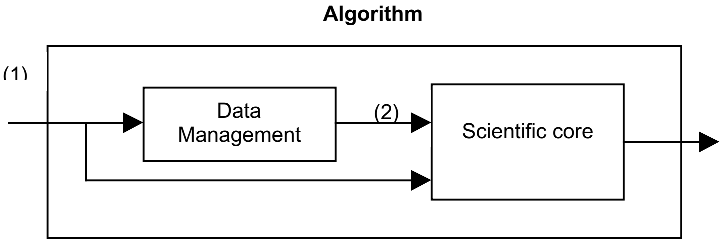
Organization of the document

- The interfaces of the processing (input and output data) are defined in section 2.
- The IONO processing algorithms are described in section 3.

The description of the processing consists of:

- An overview of the overall processing (brief description of the processing and list of functions).
- The definition and the specification of the algorithms, using the following items:
  - Name and identifier of the algorithm
  - Heritage
  - Function
  - Applicability to the various procedures
  - Algorithm definition:
    - Input data
    - Output data
    - Mathematical statement
  - Algorithm specification:
    - Input data
    - Output data
    - Processing
  - Accuracy (if any)
  - Comments (if any)
  - References (if any)

As previously mentioned, only the scientific core of each algorithm is specified in this document. For each algorithm, the input data (1) identified in the "Algorithm definition" section corresponds to the input data required for the global processing (Data Management and Scientific Core), while the input data (2) identified in the "Algorithm specification" section corresponds to the data requested for the scientific core only.



The general information necessary for a global understanding of the algorithm within the overall processing is provided in the “Algorithm definition” sections.

The detailed information required by the team in charge of the software development is provided in the “Algorithm specification” sections, which precisely define the scientific part (i.e. the core) of the algorithms.

Basic rules

The following basic rules are applied to the specification of the algorithms:

- The specifications of an algorithm are always relevant to the processing of a single data point and not to a set of data points
- Elementary functions, which are common to several algorithms (also called "mechanisms"), are specified in AD5.
- The input and output data are always identified by a precise description, an explicit name (that could be used in the coding phase), a unit and, if necessary, a reference system
- Regarding the errors that may occur during the processing functions (for example, negative argument for logarithmic or square root functions), the algorithms systematically output an execution status. The building and the management of this information will be defined during the architectural design of the software.
- Regarding the representation of tables, the following conventions are used :
  - $X[N_1:N_2]$ represents a one-dimension table whose elements are X(i) (or X_i) with $i \in [N_1, N_2]$
  - $X[N_1:N_2][M_1:M_2]$ represents a two-dimension table whose elements are X(i,j) (or X_{ij}) with $i \in [N_1,N_2]$ and $j \in [M_1,M_2]$
  - And so on

2. INPUT AND OUTPUT DATA

2.1. INPUT DATA

Two types of input data may be discriminated :

- "Product" data, which correspond to the measurements performed by DORIS:
  - DORIS level 1.0 parameters.
- Auxiliary data, which may be dynamic or static:
  - Dynamic auxiliary data are the time-varying data
  - Static auxiliary data are constant data.

The DORIS data set on input represents a sequential set of measurements.

2.1.1. PRODUCT DATA

The DORIS level 1.0 parameters are described in AD4.

2.1.2. AUXILIARY DATA

- **Dynamic auxiliary data:**

  Dynamic auxiliary data for IONO processing consist of:

  - Orbit data
  - Beacon data

- **Static auxiliary data:**

  Static auxiliary data for IONO processing consist of:

  - The DORIS instrumental characterization data, described in RD2
  - The following data described in RD2 :
    - Processing parameters (all the constant parameters used in the processing)
    - DIP file containing magnetic inclination on a regular grid in latitude, longitude, at a given time-tag

      The grid of magnetic inclination is computed with the IGRF-2000 model.

2.2. OUTPUT DATA

The IONO processing outputs :

- The DORIS derived TEC maps. Two maps are produced : one for the ascending passes and one for the descending passes.

- One set of DORIS level 1b parameters that are structured in exactly the same sequence as the set of level 1.0 input parameters.

  The DORIS level 1b parameters are considered as additional parameters produced by the IONO processing.

3. "IONO" PROCESSING

3.1. PROCESSING OVERVIEW

3.1.1. BRIEF DESCRIPTION

A brief overview of the main functions of the nominal IONO processing is given in this section. A detailed description is provided in section 3.2.

IONO processing provides TEC maps from Doris data. On nominal operation, these maps are computed on a daily basis. In order to prevent model from divergence due to boundary problems, two days of Doris measurements are used for each TEC map and include all Doris measurements from day D, measurements only from the second half of the day D - 1 and measurements from the first half of day D + 1.
The Doris data, spanning two days are organized into visibility segments acquired during a beacon visibility.

IONO processing is based on a relation between the Doris measurements (computed from the Doppler counts measured by the Doris receiver on board) and the difference of TEC values between the beginning and the end of the counting period of the Doppler cycles. The mathematical description of this relation is given in RD4.
These TEC values are located at the positions of the subionospheric points and they are expressed as a function of the vertical TEC values at grid points of a grid in geomagnetic latitude and geographic longitude, using a polynomial interpolation. The geomagnetic latitude is used here to take into account the spatial characteristics of the TEC.
In a first step, the TEC values are computed on this working grid, using a Least Square estimator.
In a second step, the TEC values are computed on an output grid in geographic latitude and geographic longitude by interpolation from the TEC values estimated on the working grid. Indeed, two grids are provided to take into account the local time difference between the ascending and descending passes.

The IONO processing is divided up into three parts :

- The first part deals with the computation of the geometrical elements required for the processing.
- The second part deals with the computation of the quality of the Doris measurements to be used for the TEC estimation.
- The third part deals with the computation of the TEC values, that is to say the estimation of the TEC values on the two geographical grids.

The computation of the geometrical elements are performed by the four functions :

- The function “LOS_ION_GTY_01 - To compute the elevation of the satellite” computes the elevation of the satellite versus the beacon.
- The two functions “LOS_ION_GTY_02 - To compute the position of the subionospheric point” and “LOS_ION_GTY_03 - To calculate the modified longitude of the subionospheric point” both deal with the computation of the position of the subionospheric point needed for the TEC estimation. The second function computes the longitude of the subionospheric point to take into account the problem of local time that may occur when the satellite is in visibility of the same beacon for two successive tracks.
- The function “LOS_ION_GTY_04 - To calculate the conversion coefficient between vertical TEC and slant TEC” calculates the coefficient needed to convert the slant TEC into vertical TEC.

The quality of the Doris measurements is assessed using the three following functions :

- The function “LOS_ION_QUA_01 - To edit the Doris measurements over each visibility segment” is used to perform a polynomial regression on the Doris measurements, for each visibility segment. This regression provides the residuals of the measurements which are considered as quality indicators of the measurements. The regression is also used to perform editing on the Doris measurements.
- The function “LOS_ION_QUA_02 - To compute quality parameters of the Doris measurements” computes the standard deviation of the residuals of the Doris measurements over the whole data set and a final editing on the Doris measurements is performed.
- The function “LOS_ION_QUA_03 - To weight the Doris measurements” computes the weights for the Doris measurements to be used in the TEC estimation.

TEC values are then estimated in the third part of the processing, as follows :

- First, the linear system issued from the equation described in RD4 is formed by the function “LOS_ION_TEC_01 - To establish the linear system for the computation of TEC on the grid in geomagnetic latitude” .
- Then, the continuity of the TEC values on the working grid is computed with the function “LOS_ION_TEC_02 - To insure TEC continuity”.
- In a first step, the TEC values are computed, using a Least Square estimator, on the working grid in geomagnetic latitude and geographic longitude in the function “LOS_ION_TEC_03 - To compute TEC values on the grid in geomagnetic latitude”.
- In a second step, the TEC values are computed on a more refined grid in geographic latitude and longitude (the output grid), by interpolation from the TEC values estimated on the working grid, in the function “LOS_ION_TEC_04 - To interpolate TEC values on the geographical grid”.

The quality of the TEC estimation is given in the end by the functions “LOS_ION_QUA_04 - To assess the quality of the TEC estimation”, "LOS_ION_QUA_05 - To compute the Doris residuals after the TEC estimation" and "LOS_ION_QUA_06 - To perform statistics on the Doris measurements after the TEC estimation".

3.1.2. TERMINOLOGY

The Doris measurements are made by two different treatment units on board of the satellite. Two measurements may have the same time tag but a different number of treatment unit.
Each algorithm described in this document for one measurement is valid for each treatment unit.
In this document, a “visibility segment” refers to the Doris measurements collected by a beacon and a treatment unit when the satellite is in visibility of this ground beacon.
The “whole data set” refers to all the Doris measurements used to produce the TEC maps. To compute the maps for the day D, the Doris measurements of the day D, the Doris measurements of the second half of the day D-1 and the first half of the day D+1, are used.
The “working grid” defines a grid in geomagnetic latitude and geographic longitude. It is also referred to as the grid in geomagnetic latitude.
The “output grid” defines a grid in geographic latitude and geographic longitude. It is also referred to as the geographical grid.
The “Doris measurement” is the value of the measurement computed from the Doppler data on both bands 2GHz and 400 MHz, provided in the Doris level 1.0 parameters.

3.1.3. LIST OF FUNCTIONS

A list of the functions of the nominal JASON-1/ENVISAT IONO processing is given in **Figure 1**.

FUNCTION
LOS_ION_GTY_01 - To compute the elevation of the satellite
LOS_ION_GTY_02 - To compute the position of the subionospheric point
LOS_ION_GTY_03 - To calculate the modified longitude of the subionospheric point
LOS_ION_GTY_04 - To calculate the conversion coefficient between vertical TEC and slant TEC
LOS_ION_QUA_01 - To edit the Doris measurements over each visibility segment
LOS_ION_QUA_02 - To compute quality parameters of the Doris measurements
LOS_ION_QUA_03 - To weight the Doris measurements
LOS_ION_TEC_01 - To establish the linear system for the computation of TEC on the grid in geomagnetic latitude
LOS_ION_TEC_02 - To insure TEC continuity
LOS_ION_TEC_03 - To compute TEC values on the grid in geomagnetic latitude
LOS_ION_TEC_04 - To interpolate TEC values on the geographical grid
LOS_ION_QUA_04 - To assess the quality of the TEC estimation
LOS_ION_QUA_05 - To compute the Doris residuals after the TEC estimation
LOS_ION_QUA_06 - To perform statistics on the Doris measurements after the TEC estimation

Figure 1: Functions of the nominal JASON-1/ENVISAT IONO processing

3.2. FUNCTIONS

A detailed description of the functions of the nominal JASON-1/ENVISAT IONO processing is given in this section.

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LOS_ION_GTY_01 - To compute the elevation of the satellite

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
Checked by:	N. PICOT	
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Algorithm change record		Date	Issue:	Update:
	Creation			
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HERITAGE

TOPEX-POSEIDON

FUNCTION

To compute the elevation of the satellite versus the beacon.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

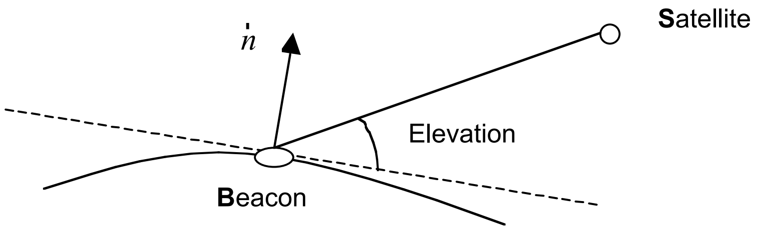
- Product data : none
- Computed data : none
- Dynamic auxiliary data:
  - Doris beacon data
    - Position of the beacon
  - Doris orbit data
    - Position of the satellite
- Static auxiliary data: none

Output data

- Elevation of the satellite

Mathematical statement

The figure presented below shows the geometry of the system.



The elevation of the satellite versus the beacon is the angle between the direction beacon-satellite (direction of the vector $\overrightarrow{(\text{Beacon}, \text{Satellite})}$, called $\overrightarrow{BS}$) and the direction tangent to the beacon (direction normal to the vector $\vec{n}$, $\vec{n}$ being the vertical to the ellipsoid of reference).
Thus elevation is calculated, using a dot product, by the following equation :

$$\text{Elevation} = A\sin\left[\frac{\vec{n}\cdot\overrightarrow{BS}}{\|\vec{n}\|\,\|\overrightarrow{BS}\|}\right] \qquad (1)$$

ALGORITHM SPECIFICATION

The following processing is performed for each Doris measurement at the beginning and at the end of the counting period. It is specified hereafter for the generic term x = bgn, end.

Warning

Computation of the position of the satellite at the beginning and the end of the counting period are considered as part of "data management and control algorithms". They are specified in the document RD1.

Input data

- Geodetic latitude of the beacon : Lat_beac (degrees)
- Geodetic longitude of the beacon : Lon_beac (degrees)
- Co-ordinate X of the beacon in the ITRF reference : X_beac (m)
- Co-ordinate Y of the beacon in the ITRF reference : Y_beac (m)
- Co-ordinate Z of the beacon in the ITRF reference : Z_beac (m)
- Co-ordinate X of the satellite in the ITRF reference : X_sat_x (m)
- Co-ordinate Y of the satellite in the ITRF reference : Y_sat_x (m)
- Co-ordinate Z of the satellite in the ITRF reference : Z_sat_x (m)

Output data

- Elevation of the satellite : Elev_x (degrees)

Processing

- To compute the unit vector normal to the beacon

  X_n = cos(Lat_beac)*cos(Lon_beac) (1)

  Y_n = cos(Lat_beac)*sin(Lon_beac) (2)

  Z_n = sin(Lat_beac) (3)

- To compute the distance beacon-satellite

$$\text{Dist\_beac\_sat} = \sqrt{(\text{X\_sat\_x} - \text{X\_beac})^2 + (\text{Y\_sat\_x} - \text{Y\_beac})^2 + (\text{Z\_sat\_x} - \text{Z\_beac})^2} \quad (4)$$

- To compute the elevation of the satellite using equation (1) from the definition section

$$\text{Tmp} = [(\text{X\_sat\_x} - \text{X\_beac}) * \text{X\_n} + (\text{Y\_sat\_x} - \text{Y\_beac}) * \text{Y\_n} + (\text{Z\_sat\_x} - \text{Z\_beac}) * \text{Z\_n}] / \text{Dist\_beac\_sat} \quad (5)$$

  Elev_x = Arcsin(Tmp) (6)

  Elev_x = Elev_x *180/Pi (7)

ACCURACY

N/A

COMMENTS

None

REFERENCES

None

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LOS_ION_GTY_02 - To compute the position of the subionospheric point

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
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	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To compute the position of the subionospheric point in the geodetic reference.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

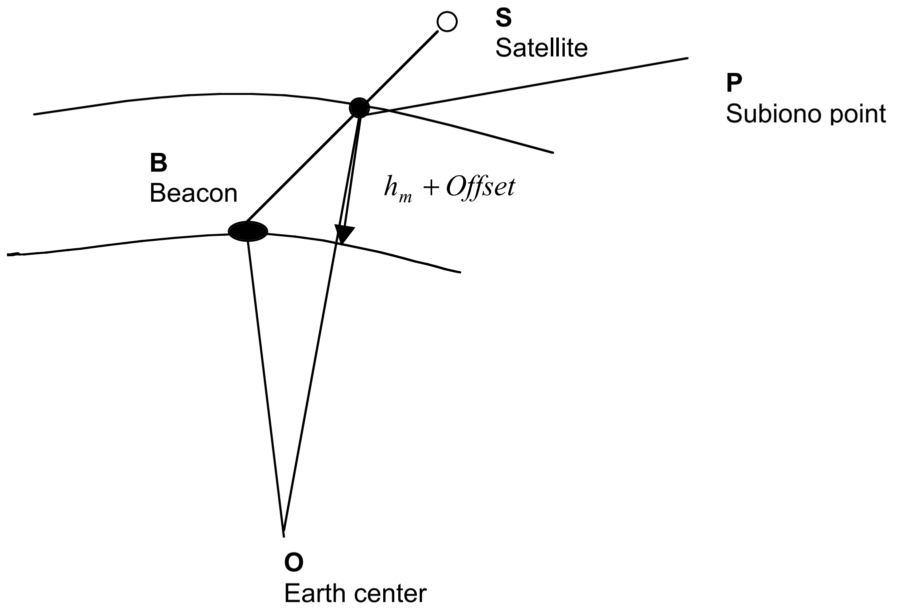
- Product data : none
- Computed data : none
- Dynamic auxiliary data:
  - Doris beacon data
    - Position of the beacon
  - Doris orbit data
    - Positions of the satellite
- Static auxiliary data:
  - Universal constants :
    - Flattening coefficient of the reference ellipsoid
    - Semi major axis of the reference ellipsoid
  - Processing parameters :
    - Altitude of the maximum of ionization
    - Offset of the altitude of the maximum of ionization
  - Processing parameters for the determination of the orbit altitude and of the latitude :
    - Desired accuracy for the orbit altitude
    - Desired accuracy for the latitude

Output data

- Geodetic position (latitude, longitude) of the subionospheric point

Mathematical statement

The figure presented below shows the geometry of the system.



The following parameters are derived from the positions of the beacon and the satellite :

$$\overrightarrow{BS} = (dX, dY, dZ)^T = (X\_sat - X\_beac, Y\_sat - Y\_beac, Z\_sat - Z\_beac)^T \tag{1}$$

$$\overrightarrow{OB} = (X\_beac, Y\_beac, Z\_beac)^T \tag{2}$$

$$\left\| \overrightarrow{OP} \right\| = Earth\_radius + h_m + Offset = R\_sub \tag{3}$$

h_m is the altitude of the maximum of ionization which is the peak of electronic content along altitude
Offset is the value of the offset fixed in the processing parameters.

The value of the offset added to the maximum of ionization has been tuned empirically using Bent model in different configurations.

The coefficient α is defined as the coefficient that gives the position of the subionospheric point on the path from the beacon to the satellite :

$$\overrightarrow{BP} = \alpha\, \overrightarrow{BS} \tag{4}$$

with α such that :

$$0 < \alpha < 1 \tag{5}$$

Thus, the position of the subionospheric point, in the geocentric reference is given by :

$$\overrightarrow{OP} = \overrightarrow{OB} + \overrightarrow{BP} = \overrightarrow{OB} + \alpha \overrightarrow{BS} \tag{6}$$

Its co-ordinates are written as :

$$X\_sub = X\_beac + \alpha * dX \tag{7}$$
$$Y\_sub = Y\_beac + \alpha * dY \tag{8}$$
$$Z\_sub = Z\_beac + \alpha * dZ \tag{9}$$

These co-ordinates are then converted into geodetic latitude and longitude.

The coefficient α is calculated using the following formula :

$$\left\|\overrightarrow{BP}\right\|^2 = \left\|\overrightarrow{BO} + \overrightarrow{OP}\right\|^2 = \left\|\overrightarrow{OB}\right\|^2 + \left\|\overrightarrow{OP}\right\|^2 + 2\,\overrightarrow{BO} \cdot \overrightarrow{OP} \tag{10}$$

Using equation (4) and (6), that gives :

$$\alpha^2 \left\|\overrightarrow{BS}\right\|^2 + 2\alpha \left(\overrightarrow{OB} \cdot \overrightarrow{BS}\right) = R\_sub^2 - \left\|\overrightarrow{OB}\right\|^2 \tag{11}$$

The coefficient α is finally calculated by :

$$\alpha = \frac{\sqrt{\left(\overrightarrow{OB} \cdot \overrightarrow{BS}\right)^2 + \left\|\overrightarrow{BS}\right\|^2 \left[R\_sub^2 - \left\|\overrightarrow{OB}\right\|^2\right]} - \left(\overrightarrow{OB} \cdot \overrightarrow{BS}\right)}{\left\|\overrightarrow{BS}\right\|^2} \quad \text{if } \overrightarrow{OB} \cdot \overrightarrow{BS} \geq 0 \tag{12}$$

$$\alpha = -\frac{\sqrt{\left(\overrightarrow{OB} \cdot \overrightarrow{BS}\right)^2 + \left\|\overrightarrow{BS}\right\|^2 \left[R\_sub^2 - \left\|\overrightarrow{OB}\right\|^2\right]} + \left(\overrightarrow{OB} \cdot \overrightarrow{BS}\right)}{\left\|\overrightarrow{BS}\right\|^2} \quad \text{if } \overrightarrow{OB} \cdot \overrightarrow{BS} < 0 \tag{13}$$

The two conditions on the dot product $\overrightarrow{OB} \cdot \overrightarrow{BS}$ are derived from the condition (5) on the coefficient α.

ALGORITHM SPECIFICATION

The processing is performed for each subionospheric point at the beginning and the end of the counting period. It is specified hereafter for the generic term x = bgn, end.

Input data

- Flattening coefficient of the reference ellipsoid : Flattening (/)
- Semi major axis of the reference ellipsoid : SM_Axis (m)
- Desired accuracy for the orbit altitude : Acc_Orb_Alt (m)
- Desired accuracy for the latitude : Acc_Lat (degree)
- Altitude of the maximum of ionization : Alt_io_max (m)
- Offset of the altitude of the maximum of ionization : Offset_alt_io_max (m)
- Co-ordinate X of the beacon in the ITRF reference : X_beac (m)
- Co-ordinate Y of the beacon in the ITRF reference : Y_beac (m)
- Co-ordinate Z of the beacon in the ITRF reference : Z_beac (m)
- Co-ordinate X of the satellite in the ITRF reference : X_sat_x (m)
- Co-ordinate Y of the satellite in the ITRF reference : Y_sat_x (m)
- Co-ordinate Z of the satellite in the ITRF reference : Z_sat_x (m)

Output data

- Latitude of the subionospheric point : Lat_sub_x (degrees) ($\in$ [-90 : +90])
- Longitude of the subionospheric point : Lon_sub_x (degrees) ($\in$ [0:360[ )

Processing

- To compute $\left\|\overrightarrow{OB}\right\|^2$

$$\text{Norm\_2\_OB} = \text{X\_beac}^2 + \text{Y\_beac}^2 + \text{Z\_beac}^2 \quad (1)$$

- To compute $\left\|\overrightarrow{BS}\right\|^2$

$$\text{Norm\_2\_BS} = (\text{X\_sat\_x} - \text{X\_beac})^2 + (\text{Y\_sat\_x} - \text{Y\_beac})^2 + (\text{Z\_sat\_x} - \text{Z\_beac})^2 \quad (2)$$

- To compute the dot product $\overrightarrow{OB} \cdot \overrightarrow{BS}$

$$\text{Dot\_prod} = (\text{X\_sat\_x} - \text{X\_beac})*\text{X\_beac} + (\text{Y\_sat\_x} - \text{Y\_beac})*\text{Y\_beac} + (\text{Z\_sat\_x} - \text{Z\_beac})*\text{Z\_beac} \quad (3)$$

- To compute the coefficient α

$$Aux = Dot\_prod^2 + Norm\_2\_BS * [(SM\_axis + Alt\_io\_max + Offset\_alt\_io\_max)^2 - Norm\_2\_OB] \quad (4)$$

If (Dot_prod ≥ 0) then

$$Alpha = \frac{\sqrt{Aux} - Dot\_prod}{Norm\_2\_BS} \quad (5)$$

Else (Dot_prod < 0) then

$$Alpha = -\frac{\sqrt{Aux} + Dot\_prod}{Norm\_2\_BS} \quad (6)$$

- To compute the co-ordinates of the subionospheric point in the ITRF reference :

$$X\_sub = X\_beac + Alpha * (X\_sat\_x - X\_beac) \quad (7)$$

$$Y\_sub = Y\_beac + Alpha * (Y\_sat\_x - Y\_beac) \quad (8)$$

$$Z\_sub = Z\_beac + Alpha * (Z\_sat\_x - Z\_beac) \quad (9)$$

- To compute the latitude and longitude of the subionospheric point (Lat_sub_x and Lon_sub_x expressed in degrees), using mechanism " GEN_MEC_CON_06 - Conversion of a position vector from Cartesian to geodetic co-ordinates ", with the following inputs :
  - Position of the subionospheric point :
  - X co-ordinate : X_sub (m)
  - Y co-ordinate : Y_sub (m)
  - Z co-ordinate : Z_sub (m)
- Characteristics of the reference ellipsoid :
  - Semi major axis : SM_Axis (m)
  - Flattening : Flattening (/)
- Thresholds for the iterative process:
  - Desired accuracy for the orbit altitude : Acc_Orb_Alt (m)
  - Desired accuracy for the latitude : Acc_Lat (degree)

The outputs are the following ones :

- Orbit altitude of the subionospheric point : unused
- Latitude of the subionospheric point : Lat_sub_x (degree)
- Longitude of the subionospheric point : Lon_sub_x (degree [0, 360[)

ACCURACY

N/A

COMMENTS

None

REFERENCES

None

Affaires Techniques Projets et Services Opérationnels
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31401 TOULOUSE CEDEX 4

LOS_ION_GTY_03 - To calculate the modified longitude of the subionospheric point

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
Checked by:	N. PICOT	
Approved by:	P. VINCENT	

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Algorithm change record	Creation	date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To modify the longitude of the subionospheric point because of difference of local time.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data :
  - Time-tag of the Doppler measurement
- Computed data :
  - From "LOS_ION_GTY_02 - To compute the position of the subionospheric point"
    - Latitude of the subionospheric point
    - Longitude of the subionospheric point
- Dynamic auxiliary data:
  - Doris beacon data
    - Position of the beacon
  - Doris orbit data
    - Positions of the satellite
- Static auxiliary data:
  - Doris instrumental characterization data:
    - Duration of the counting period
  - Processing parameters
    - Maximal latitude of the satellite

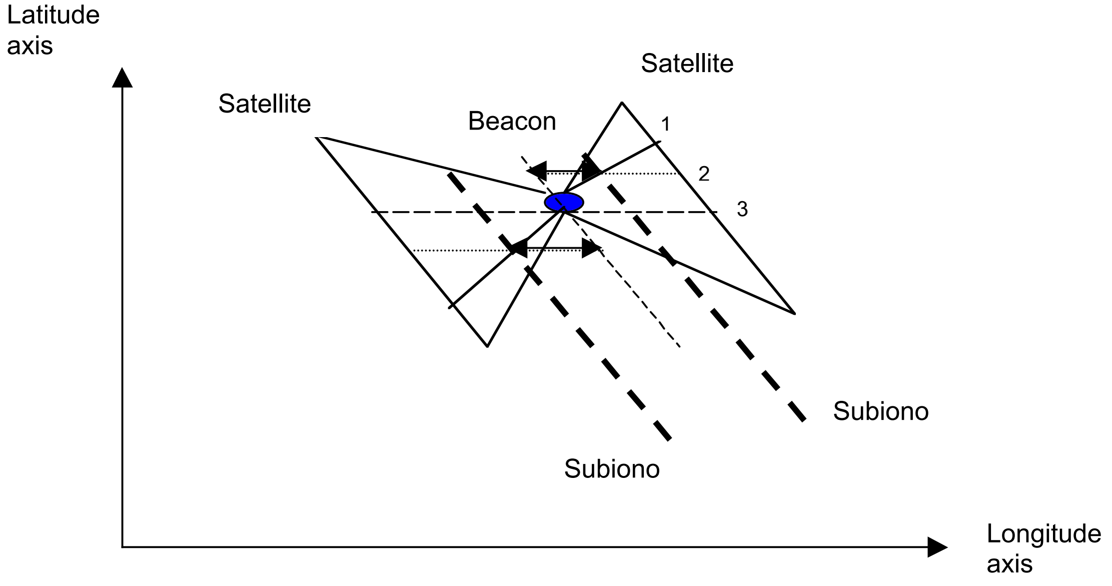
Output data

- Modified longitude of subionospheric point
- Difference of local time between subionospheric point and the point along satellite track, at the latitude of the subionospheric point

Mathematical statement

Computation of the modified longitude of subionospheric point

When two successive tracks of the satellite are in visibility of the same beacon, the two subionospheric points associated have a different local time although they are seen by the same beacon (see the figure below). In order to avoid creation of an artificial TEC slope versus longitude, due to this geometrical configuration, the longitude of the subionospheric point is translated to the one related to the beacon. The latitude of the subionospheric point remains unchanged. This approximation induces little or no deterioration of the TEC precision.



Satellite point 1 in the above figure defines the position on the satellite track. Satellite point 2 defines a point on the satellite track that gives the longitude of the satellite at the latitude of the subionospheric point. Similarly, satellite point 3 defines a point on the satellite track that gives the longitude of the satellite at the beacon latitude.

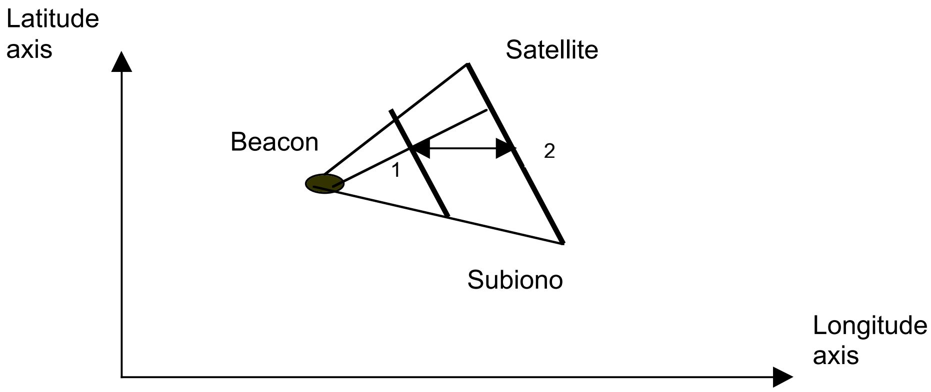
The modified longitude is computed by the following formula :

Long of subionospheric point = Long of satellite point 2 +
(Long of the beacon – Long of satellite point 3) (1)

Then, the longitude of the subionospheric point is normalized according to the longitude of satellite point 1. This normalization is realized in order to insure the continuity of the longitude for the measurements located at the poles. The longitude of the subionospheric point is such that :

$|$Lon of subionospheric point - Long of satellite point 1$|$ < 180.

Computation of local time difference



Points 1 and 2 in the above figure have the same latitude but point 1 is at the longitude of the subionospheric point and point 2 is at the longitude of the satellite.

Local time difference between the points 1 and 2 is deduced from the longitudes and local times of these two points:

Dif_loc_time = Local time of subionospheric point 1– Local time of satellite point 2

= Time-tag of subionospheric point 1 + Long of subionospheric point 1 * 86400 / 360

– Local time of satellite point 2 (2)

Where Time-tag of subionospheric point 1 is calculated using the time-tag of the measurement which is made at the middle of the counting period.

ALGORITHM SPECIFICATION

The processing is performed for each subionospheric point, at the beginning and the end of the counting period. It is specified hereafter for the generic term x = bgn, end

Warning

- The computation of the rearranged satellite positions and local time
- The computation of the longitude of the satellite at the beacon latitude
- The computation of the longitude of the satellite at the beginning of the counting period
- The computation of the time-tag of the subionospheric point

- The computation of the beacon longitude

are considered as part of “data management and control algorithms”. They are specified in the document RD1.

Input data

- Maximal latitude of the satellite : Lat_sat_max (degrees)
- Time-tag of the subionospheric point : Time_tag_sub_x (s)
- Latitude of subionospheric point : Lat_sub_x (degrees)
- Longitude of subionospheric point : Lon_sub_x (degrees)
- Longitude of the beacon : Lon_beac (degrees)
- Longitude of the satellite at the beacon latitude : Lon_sat_beac (degrees)
- Longitude of the satellite at the beginning of the counting period : Lon_sat_bgn (degrees)
- Rearranged satellite positions and local time :
  - Number of satellite positions : Nb_pos_sat (/)
  - For each satellite position :
    - Time-tag : Time_sat [0:Nb_pos_sat-1] (s)
    - Type of the pass for the satellite position : Type_sat [0:Nb_pos_sat-1] (asc or desc)
    - Latitude of the satellite : Lat_sat [0:Nb_pos_sat-1] (degrees)
    - Longitude of the satellite (modified longitude) : Lon_sat_cont [0:Nb_pos_sat-1] (degrees)
    - Local time of the satellite : Local_time_sat [0:Nb_pos_sat-1] (s)

Output data

- Modified longitude of subionospheric point : Lon_sub_new_x (degrees)
- Difference of local time between subionospheric point and satellite track
  : Dif_loc_time_x (s) $\in$ [-43200:43200]

Processing

- To compute the modified longitude of the subionospheric point, using equation (1) in the definition :
  - To compute the longitude of the satellite and its local time at the latitude of subionospheric point

    The satellite longitude (Lon_sat_sub_x) and the local time (Local_time_sat_sub_x) are computed using mechanism “GEN_MEC_SEL_02 - Selection of the satellite longitude and local time for a given latitude”, with the following inputs :
    - The latitude of the subionospheric point : Lat_sub_x
    - The time-tag of the subionospheric point : Time_tag_sub_x
    - The rearranged satellite positions and local time
      : Nb_pos_sat
      : Time_sat [0:Nb_pos_sat-1]
      : Type_sat [0:Nb_pos_sat-1]

: Lat_sat [0:Nb_pos_sat-1]

: Lon_sat_cont [0:Nb_pos_sat-1]

: Local_time_sat [0:Nb_pos_sat-1]

  * Maximal latitude of the satellite : Lat_sat_max

- Two flags (Flag_lat_max and Flag_pass) are provided by the mechanism :

  If (Flag_lat_max is "invalid" or Flag_pass is "invalid") then Lon_sat_sub_x = Lon_sub_x (1)

- To compute the modified longitude of the subionospheric point
  * If Lon_sat_beac has a default value then

    Lon_sub_new_x = Lon_sat_sub_x (2)

  * Else the modified longitude of the subionospheric point is computed by :

    Lon_sub_new_x = Lon_sat_sub_x + (Lon_beac – Lon_sat_beac) (3)

- To normalize the longitude of the subionospheric point

  While (Lon_sub_new_x – Lon_sat_bgn > 180) then

  Lon_sub_new_x = Lon_sub_new_x – 360 (4)

  While (Lon_sub_new_x – Lon_sat_bgn < -180) then

  Lon_sub_new_x = Lon_sub_new_x + 360 (5)

- To compute the difference of local time between subionospheric point and the point along satellite track at the latitude of subionospheric point.
  - If (Flag_lat_max is "invalid") then Dif_local_time_x = 43200 (6)
  - If (Flag_pass is "invalid") then Dif_local_time_x = 0 (7)
  - Else the difference of local time is computed using equation (2) given in the definition :
    * Dif_local_time_x = Time_tag_sub_x + Lon_sub_x * 86400 / 360 – Local_time_sat_sub_x (8)
    * Normalization of k*86400 to have Dif_local_time_x $\in$ [-43200 : +43200]

ACCURACY

N/A

COMMENTS

The modified longitude of the subionospheric point can be computed in a more straightforward way. The modified longitude is directly set to the beacon longitude.

REFERENCES

None

Affaires Techniques Projets et Services Opérationnels
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LOS_ION_GTY_04 - To calculate the conversion coefficient between vertical TEC and slant TEC

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
Checked by:	N. PICOT	
Approved by:	P. VINCENT	

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Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To calculate the conversion coefficient between vertical TEC and slant TEC.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data : none
- Computed data :
  - From ”LOS_ION_GTY_01 - To compute the elevation of the satellite”
    - Elevation of the satellite
- Dynamic auxiliary data: none
- Static auxiliary data:
  - Processing parameters
    - Semi major axis of the reference ellipsoid
    - Altitude of the maximum of ionization
    - Offset of the altitude of the maximum of ionization

Output data

- Conversion coefficient between vertical TEC and slant TEC

Mathematical statement

The conversion coefficient between vertical TEC and slant TEC, called k, is such that :

$$TEC_{slant} = k\ TEC_{ver} \tag{1}$$

The coefficient k is calculated by :

$$k = \frac{r}{\sqrt{r^2 - (R * \cos E)^2}} \tag{2}$$

with $$r = R + h_m + Offset \tag{3}$$

where

R is the semi major axis of the reference ellipsoid

h_m is the altitude of the maximum of ionization

Offset is the offset applied to the altitude of the maximum of ionization

E is the satellite elevation versus beacon

The value of the offset added to the maximum of ionization has been tuned empirically using Bent model in different configurations.

ALGORITHM SPECIFICATION

The processing is performed for each measurement at the beginning and the end of the counting period. It is specified hereafter for the generic term x = bgn, end.

Input data

- Semi major axis of the reference ellipsoid : SM_axis (m)
- Offset of the altitude of the maximum of ionization : Offset_alt_io_max (m)
- Altitude of the maximum of ionization : Alt_io_max (m)
- Elevation of the satellite : Elev_x (degrees)

Output data

- Conversion coefficient between vertical TEC and slant TEC : K_x (/)

Processing

The conversion coefficient between vertical TEC and slant TEC is computed using equations (2) and (3).

$$R = SM\_axis + Alt\_io\_max + Offset\_alt\_io\_max \quad (1)$$

$$Elev\_x = Elev\_x * Pi/180 \quad (2)$$

$$K\_x = \frac{R}{\sqrt{R^2 - (SM\_axis * \cos(Elev\_x))^2}} \quad (3)$$

ACCURACY

N/A

COMMENTS

None

REFERENCES

None

Affaires Techniques Projets et Services Opérationnels
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31401 TOULOUSE CEDEX 4

LOS_ION_QUA_01 - To edit the Doris measurements over each visibility segment

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
Checked by:	N. PICOT	
Approved by:	P. VINCENT	

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Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To edit the Doris measurements, using polynomial regression on the Doris measurements over a visibility segment. The residuals computed from the regression are also used in further processing for the weighting of the Doris measurements.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data :
  - Doris data
- Computed data :
  - From "LOS_ION_GTY_04 - To calculate the conversion coefficient between vertical TEC and slant TEC"
    - Conversion coefficient between vertical TEC and slant TEC at the beginning of the counting period
    - Conversion coefficient between vertical TEC and slant TEC at the end of the counting period
  - From "LOS_ION_GTY_02 - To compute the position of the subionospheric point"
    - Latitude of subionospheric point at the beginning of counting period
    - Latitude of subionospheric point at the end of counting period
- Dynamic auxiliary data: none
- Static auxiliary data:
  - Processing parameters
    - Minimum degree of the polynomial of the adjustment
    - Maximum degree of the polynomial of the adjustment
    - Threshold on the number of measurements of the visibility segment for the polynomial degree
    - Minimum number of estimates requested for the compression
    - Minimum value of the standard deviation for outliers identification
    - Standard deviation scale factor for outliers identification

Output data

- Standard deviation of the adjustment over the visibility segment
- Residuals of the adjustment

- Flags on the residuals

Mathematical statement

The aim of this function is to adjust the Doris measurements through a polynomial, fitting the TEC data. This adjustment is done to get an indicator of the quality of the Doris measurements for editing the measurements over the visibility segment and for further processing (computation of the weights of the measurements). The polynomial is just function of latitude as this is the most significant dimension for the TEC values.

The equation which links the Doris measurement and the TEC values is the following one:

$$\mathrm{mes(i)} = c_1\left[k_1 \mathrm{TEC1(i)} - k_2 \mathrm{TEC2(i)}\right] \tag{1}$$

where

mes(i) is the ith Doris measurement

c_1 is a parameter to link Doris measurement and TEC value

TEC1(i) is the TEC value at subionospheric point related to measurement i at the beginning of counting period

TEC2(i) is the TEC value at subionospheric point related to measurement i at the end of counting period

k_1 is the conversion coefficient between vertical TEC and slant TEC of the subionospheric point, at the beginning of the counting period

k_2 is the conversion coefficient between vertical TEC and slant TEC of the subionospheric point, at the end of the counting period

The model for the TEC values is a polynomial of degree N, function of the latitude of subionospheric point. Actually, the degree is fixed to a minimum or a maximum according to the number of measurements of the set. The expressions (2) and (3) presented below are given for a degree 5.

$$\mathrm{TEC1(i)} = a_0 + a_1 \mathrm{lat1(i)} + a_2 \mathrm{lat1(i)}^2 + a_3 \mathrm{lat1(i)}^3 + a_4 \mathrm{lat1(i)}^4 + a_5 \mathrm{lat1(i)}^5 \tag{2}$$

$$\mathrm{TEC2(i)} = a_0 + a_1 \mathrm{lat2(i)} + a_2 \mathrm{lat2(i)}^2 + a_3 \mathrm{lat2(i)}^3 + a_4 \mathrm{lat2(i)}^4 + a_5 \mathrm{lat2(i)}^5 \tag{3}$$

where

lat1(i) is the latitude of subionospheric point i at the beginning of counting period

lat2(i) is the latitude of subionospheric point i at the end of counting period

Thus, the computed measurement $mest(i)$ can be expressed by:

$$\begin{aligned} mest(i) = {} & c_1\left[k_1 - k_2\right]a_0 + c_1\left[k_1 lat1(i) - k_2 lat2(i)\right]a_1 + c_1\left[k_1 lat1(i)^2 - k_2 lat2(i)^2\right]a_2 \\ & + c_1\left[k_1 lat1(i)^3 - k_2 lat2(i)^3\right]a_3 + c_1\left[k_1 lat1(i)^4 - k_2 lat2(i)^4\right]a_4 \\ & + c_1\left[k_1 lat1(i)^5 - k_2 lat2(i)^5\right]a_5 \end{aligned} \quad (4)$$

Fitting this model to the Doris measurements, it becomes, under a matrix form :

$$Mes = BX \quad (5)$$

where

$$Mes = \begin{bmatrix} mes(1) \\ mes(i) \\ mes(nmes) \end{bmatrix}$$ is the vector of the Doris measurements

$$X = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix}$$ is the vector of unknown polynomial coefficients

B is the matrix of size nmes*6. One row i of B, corresponding to measurement i has the expression presented hereafter:

$$B_{i1} = c_1\left[k_1 - k_2\right] \quad (6)$$

$$B_{i2} = c_1\left[k_1\, lat1(i) - k_2\, lat2(i)\right] \quad (7)$$

$$B_{i3} = c_1\left[k_1\, lat1(i)^2 - k_2\, lat2(i)^2\right] \quad (8)$$

$$B_{i4} = c_1\left[k_1\, lat1(i)^3 - k_2\, lat2(i)^3\right] \quad (9)$$

$$B_{i5} = c_1\left[k_1\, lat1(i)^4 - k_2\, lat2(i)^4\right] \quad (10)$$

$$B_{i6} = c_1\left[k_1\, lat1(i)^5 - k_2\, lat2(i)^5\right] \quad (11)$$

The system (5) is solved using the Least Square method and a QR factorization. The residuals on the Doris measurements are then computed.

The editing on the Doris measurements is an iterative process which performs the adjustment of the Doris measurements described above, for each visibility segment, and then the outliers rejection according to a “scale” sigma test.
Once the Doris measurements have been selected, the standard deviation of the adjustment for each visibility segment is computed.

ALGORITHM SPECIFICATION

The following processing is performed for each visibility segment.

Warning

- The computation of the parameter to link Doris measurements and the TEC values
- The computation of the number of measurements of the visibility segment
- The computation of the Doris measurements
- The flags on the Doris measurements

are considered as part of "data management and control algorithms". This is specified in the document RD1.

Input data

- Parameter to link Doris measurement and the TEC values : Par_dor_TEC (m / s / 0.1 TECU)
- Minimum degree of the polynomial of the adjustment : Min_deg_pol (/)
- Maximum degree of the polynomial of the adjustment : Max_deg_pol (/)
- Threshold on the number of measurements of the visibility segment for the polynomial degree : Thres_nb_mes_pol (/)
- Number of measurements of the visibility segment : Nb_mes (/)
- Doris measurement : Dor_mes [0:Nb_mes-1] (m/s)
- Validity flag for the Doris measurement : Dor_mes_val_flag [0:Nb_mes-1] (1)
- Latitude of subionospheric point at the beginning of counting period for all the measurements of the visibility segment : Lat_sub_bgn [0:Nb_mes-1] (degrees)
- Latitude of subionospheric point at the end of counting period for all the measurements of the visibility segment : Lat_sub_end [0:Nb_mes-1] (degrees)
- Conversion coefficient between vertical TEC and slant TEC at the beginning of counting period : K_bgn [0:Nb_mes-1] (/)
- Conversion coefficient between vertical TEC and slant TEC at the end of counting period : K_end [0:Nb_mes-1] (/)
- Minimum number of estimates requested for the compression : Min_pts (/)
- Minimum value of the standard deviation for outliers identification : Min_std (m/s)
- Standard deviation scale factor for outliers identification : Scale (/)

Output data

- Standard deviation of the adjustment over the visibility segment : Std_qual_visi (m/s)
- Residuals of the adjustment : Qual_mes [0:Nb_mes-1] (m/s)
- Flags on the residuals : Map_res [0:Nb_mes-1] (1)

(1) 2 states: "valid" or "invalid"

Processing

- If Nb_mes = 0 or if there is no measurement (j) such that the validity flags for the Doris measurements (Dor_mes_val_flag(j)) are set to "valid", then:
  - Std_qual_visi is set to a default value
  - The residuals for the visibility segment Qual_mes(j) are set to default values
  - The output flags Map_res are set to “invalid”
- Else :
  - The set of selected measurements (i.e. the set of measurements to be edited) is first restricted to the measurements Dor_mes(j) of the visibility segment such that Dor_mes_val_flag(j) are "valid". The same selection is done for the corresponding values of K_bgn(j), K_end(j), Lat_sub_bgn(j) and Lat_sub_end(j)
  - Then, the following iterative process (steps 1 to 3) is performed until Nb_mes_val is constant ("normal ending"), or until it is stopped ("iterative process break").

    ∗ Step 1 (Test of Nb_mes_val):

    Let Nb_mes_val be the current number of selected measurements.

    ◊ If $\text{Nb\_mes\_val} < \text{Min\_pts}$, then the iterative process is stopped ("iterative process break")

    ◊ Else if Nb_mes_val is unchanged with respect to the previous iteration (condition to be ignored for the first call), then the iterative process is stopped ("normal ending")

    ◊ Else the following steps of the iterative process are performed.

    ∗ Step 2 (Polynomial regression and computation of the standard deviation):

    ◊ To compute the matrix B of the polynomial regression

    ⇒ To set the polynomial degree according to the number of selected measurements of the visibility segment (Nb_mes_val) :

    - For a visibility segment which contains less than Thres_nb_mes_pol measurements, the polynomial is of degree Min_deg_pol, and so dimension of the vector of polynomial coefficients (N_pol) is fixed to Min_deg_pol+1.
    - For a visibility segment which contains more than Thres_nb_mes_pol measurements, the polynomial is of degree Max_deg_pol, and so dimension of the vector of polynomial coefficients (N_pol) is fixed to Max_deg_pol+1.

    ⇒ To compute matrix B from equations (6), (7), (8), (9), (10) and (11) :

    Coefficient B(i,j) of matrix B is calculated by:

    $$B(i,j) = \text{Par\_dor\_TEC} * (\text{K\_bgn}(i)*\text{Lat\_sub\_bgn}(i)^{j} - \text{K\_end}(i)*\text{Lat\_sub\_end}(i)^{j}) \quad (1)$$

    with $i \in [0, \text{Nb\_mes\_val} - 1]$ and $j \in [0, \text{N\_pol} - 1]$

    ◊ To perform the adjustment on the valid measurements of the visibility segment, using “GEN_MEC_COM_07 - Polynomial regression / Least Square method” with the following inputs :

Number of measurements	: Nb_mes_val (/)
Set of measurements	: Dor_mes [0:Nb_mes_val-1]
Number of polynomial coefficients	: N_pol (/)
Matrix of the polynomial regression	: B [0:Nb_mes_val-1] [0:N_pol-1]

The outputs of the algorithm are the following ones :

Adjusted measurements	: (unused values)
Residuals on the measurements	: Qual_mes [0:Nb_mes_val-1]
Standard deviation of the residuals	: Std_qual_visi

∗ Step 3 (Update of the selected measurements):

◊ If $\text{Std\_qual\_visi} \le \text{Min\_std}$, then the set of selected measurements is unchanged

◊ Else $(\text{Std\_qual\_visi} > \text{Min\_std})$ then the set of selected measurements is restricted to the measurements Dor_mes(j) such that :

$$|\text{Qual\_mes(j)}| \le \text{Scale} * \text{Std\_qual\_visi} \qquad (2)$$

the same selection is applied to K_bgn(j), K_end(j), Lat_sub_bgn(j) and Lat_sub_end(j)

◊ Step 1 of the iterative process is then performed.

– Flags Map_res(j) of the map of valid measurements are set to "valid" for the measurements belonging to the last set of selected measurements, while they are set to "invalid" for the other measurements of the visibility segment.

ACCURACY

N/A

COMMENTS

- The degrees minimum and maximum of the polynomial (Min_deg_pol and Max_deg_pol) are set to 3 and 5, respectively.

  Further analysis of cases will help to decide if the polynomial of degree 5 is of interest or if the degree 3 is good enough to adjust the Doris measurements.

- The TECU is the TEC Unit and 1 TECU = 10^{16} electrons/m^2

REFERENCES

NONE

Affaires Techniques Projets et Services Opérationnels
Sous-Direction Etudes Systèmes et Développements
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LOS_ION_QUA_02 - To compute quality parameters of the Doris measurements

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
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Approved by:	P. VINCENT	

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Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

POSEIDON-1

FUNCTION

To compute the standard deviation of the adjustment of the Doris measurements over the whole data set and to perform final editing on Doris measurements depending on this standard deviation.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data :
  - Doris data
- Computed data :
  - From "LOS_ION_QUA_01 - To edit the Doris measurements over each visibility segment" :

    For each visibility segment :
    - Standard deviation of the adjustment
    - Quality (residuals) of the adjustment
    - Flags on the residuals
- Dynamic auxiliary data: none
- Static auxiliary data:
  - Processing parameters
    - Constant for measurements threshold
    - Maximal value of standard deviation allowed for the adjustment of the visibility segment

Output data

- Standard deviation of the adjustment over the whole data set
- Flags on the measurements of each visibility segment after editing

Mathematical statement

The standard deviation of the adjustment over the whole data set is computed using all the valid residuals of the polynomial adjustment performed on each visibility segment, such that the standard deviation of the visibility segment is under a threshold.
Then editing is performed using the residuals and the standard deviation over the whole data set.

ALGORITHM SPECIFICATION

Warning

The computation of :
- the number of measurements of the visibility segment
- the number of visibility segments

are considered as part of "data management and control algorithms". They are specified in the document RD1.

Input data

- Number of visibility segments : Nb_visi_seg (/)
- For each visibility segment :
  - Number of Doris measurements : Nb_mes [0:Nb_visi_seg-1] (/)
  - Standard deviation of the adjustment : Std_qual_visi [0:Nb_visi_seg-1] (m/s)
  - Quality (residuals) of the adjustment : Qual_mes [0:Nb_visi_seg-1] [0:Nb_mes-1] (m/s)
  - Flags on the residuals residuals : Map_res [0:Nb_visi_seg-1] [0:Nb_mes-1] (1)
- Constant for measurements threshold : Cst_threshold (/)
- Maximal value of standard deviation allowed for the adjustment of the visibility segment : Std_qual_max (m/s)

Output data

- Standard deviation of the adjustment over the whole data set : Std_qual_glob (m/s)
- For each visibility segment :
  - Flags on the measurements of each visibility segment after editing : Final_edit_flag [0:Nb_visi_seg-1] [0:Nb_mes-1] (1)

(1) 2 states: "valid" or "invalid"

Processing

- All the flags Final_edit_flag (k) and Flag(k) are initialized to "invalid"

- The standard deviation of the adjustment over the whole data set is computed according to the following way :
  - To select the visibility segments to be used in the computation of the standard deviation.

    The following test is performed for each visibility segment :

    If (Std_qual_visi(i) < Std_qual_max), the visibility segment i is taken into account to compute the standard deviation over the whole data set and the flags of the measurements of the visibility segment Flag (j) are set to "valid" (j =0, Nb_mes(i)-1).

    Else the flags Flag (j) are set to "invalid".
  - To compute the standard deviation with the selected visibility segments

    The standard deviation of the adjustment over the whole data set (Std_qual_glob) is calculated, using mechanism "GEN_MEC_COM_01 - Arithmetic averaging", with the residuals of the adjustment of the Doris measurements {Qual_mes(k)} for all the measurements such that the flags Flag(k) and Map_res(k) are "valid".

- Editing on the Doris measurements is performed, using the standard deviation of the adjustment over the whole data set :

  The flags Final_edit_flag (k) of the map of valid measurements are set to "valid" for the Doris measurements k of the whole data set such that :

  Map_res(k) and Flag(k) are "valid" and | Qual_mes(k) | < Cst_threshold * Std_qual_glob

ACCURACY

N/A

COMMENTS

The Doris measurements selected by this function will be used in the TEC estimation.

REFERENCES

None

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31401 TOULOUSE CEDEX 4

LOS_ION_QUA_03 - To weight the Doris measurements

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
Checked by:	N. PICOT	
Approved by:	P. VINCENT	

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Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To weight the Doris measurements

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data : none
- Computed data :
  - From "LOS_ION_GTY_03 - To calculate the modified longitude of the subionospheric point"
    - Difference of local time at the beginning of the counting period
  - From "LOS_ION_QUA_01 - To edit the Doris measurements over each visibility segment" :

    For each visibility segment :
    - Standard deviation of the adjustment
    - Quality (residuals) of the adjustment
  - From "LOS_ION_QUA_02 - To compute quality parameters of the Doris measurements"
    - Standard deviation of the adjustment over the whole data set
- Dynamic auxiliary data: none
- Static auxiliary data:
  - Processing parameters
    - Constant weight term
    - Weight term for the standard deviation of the visibility segment
    - Weight term for the quality of the measurement
    - Weight term for local time difference of the measurement

Output data

- Weight of the Doris measurement

Mathematical statement

The model used to weight the measurements takes into account the quality and the geometrical features of each Doris measurement and of the visibility segment containing the measurement.

ALGORITHM SPECIFICATION

The processing is performed for each Doris measurement of the whole data set.

Input data

- Constant weight term : W_cst (/)
- Weight term for the standard deviation of the visibility segment : W_std_visi (/)
- Weight term for the quality of the measurement : W_qual_mes (/)
- Weight term for local time difference of the measurement : W_dif_loc_time_mes (/)
- Difference of local time at the beginning of the counting period : Dif_loc_time_bgn (s)
- Standard deviation of the adjustment over the whole data set : Std_qual_glob (m/s)
- Standard deviation of the adjustment for the visibility segment : Std_qual_visi (m/s)
- Quality (residual) of the Doris measurement : Qual_mes (m/s)

Output data

- Weight of the measurement : Weight (/)

Processing

- To compute the weight of Doris measurement

$$\mathrm{Weight\_tmp} = \left[\mathrm{Std\_qual\_glob}^2 + \mathrm{W\_std\_visi} * \mathrm{Std\_qual\_visi}^2 + \mathrm{W\_qual\_mes} * \mathrm{Qual\_mes}^2\right] * \left[1 + \mathrm{W\_dif\_loc\_time\_mes} * \mathrm{Dif\_loc\_time\_bgn}^2\right] \quad (1)$$

$$\mathrm{Weight} = \frac{1}{\mathrm{W\_cst} * \mathrm{Weight\_tmp}} \quad (2)$$

ACCURACY

N/A

COMMENTS

The values assigned to the weight terms will be settled in the verification phase.

REFERENCES

None

Affaires Techniques Projets et Services Opérationnels
Sous-Direction Etudes Systèmes et Développements
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31401 TOULOUSE CEDEX 4

LOS_ION_TEC_01 - To establish the linear system for the computation of TEC on the grid in geomagnetic latitude

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
Checked by:	N. PICOT	
Approved by:	P. VINCENT	

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Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

This processing is performed for ascending and descending measurements using the equation established for the TEC estimation.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data :
  - Doris data spanning two days
- Computed data :
  - From "LOS_ION_QUA_03 - To weight the Doris measurements"
    - Weights of the Doris measurements
  - From "LOS_ION_GTY_04 - To calculate the conversion coefficient between vertical TEC and slant TEC"
    - Conversion coefficient between vertical TEC and slant TEC at the beginning of the counting period
    - Conversion coefficient between vertical TEC and slant TEC at the end of the counting period
  - From "LOS_ION_GTY_02 - To compute the position of the subionospheric point"
    - Latitude of subionospheric point at the beginning of the counting period
    - Latitude of subionospheric point at the end of the counting period
  - From "LOS_ION_GTY_03 - To calculate the modified longitude of the subionospheric point"
    - Longitude of subionospheric point at the beginning of the counting period
    - Longitude of subionospheric point at the end of the counting period
  - From "LOS_ION_QUA_02 - To compute quality parameters of the Doris measurements"
    - Flags on the measurements after final editing
- Dynamic auxiliary data:
  - Doris orbit data
- Static auxiliary data:
  - Processing parameters
    - Degree of interpolation along latitude

    * Degree of interpolation along longitude
    * Offset on the limits of the working grid in longitude
    * Features of the ascending working grid
    * Features of the descending working grid
  - Dip data

Output data

- Flag on the Doris measurement used for the TEC estimation
- Matrix and right hand side containing information of the measurement of kind Type (Type = asc or desc)
- Quality index of the LS method for the measurement of kind Type (Type = asc or desc)
- Geomagnetic latitude of the subionospheric point, at the beginning and the end of the counting period

Mathematical statement

The equation used for the TEC estimation is the following one :

$$\mathrm{dmes}(n) = c_1\,[k_1\,\mathrm{TEC1}(n) - k_2\,\mathrm{TEC2}(n)] \tag{1}$$

where $\mathrm{dmes}(n)$ is the value of Doris measurement n

c_1 is a parameter of the processing to link Doris measurement and TEC value

k_1 is the conversion coefficient between vertical TEC and slant TEC of subionospheric point n, at the beginning of the counting period

$\mathrm{TEC1}(n)$ is the TEC value of subionospheric point n, at the beginning of the counting period

k_2 is the conversion coefficient between vertical TEC and slant TEC of subionospheric point n, at the end of the counting period

$\mathrm{TEC2}(n)$ is the TEC value of subionospheric point n, at the end of the counting period

$\mathrm{TEC1}(n)$ (or $\mathrm{TEC2}(n)$) can be expressed as an interpolation of the TEC values located at the grid points surrounding the subionospheric point. This is written as :

$$X1(n) = \sum_{k \in K_1} \alpha_k X_k \tag{2}$$

$$X2(n) = \sum_{k \in K_2} \beta_k X_k \tag{3}$$

α_k and β_k are the coefficients computed by polynomial interpolation of the grid points surrounding each one of the subionospheric points

X_j are the TEC values of the working grid points which are used in the interpolation

K_1 and K_2 are the indexes of the grid points surrounding the subionospheric points 1 and 2

The interpolation is of degree M for longitude and degree N for latitude (that is to say MN points of the working grid are used to interpolate the TEC values at grid points surrounding the subionospheric point). The degrees of interpolation M and N are parameters of the processing. In most cases, they are such that M = N = 4.
Mathematical developments about the interpolation are given in mechanism "GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid". Further details on the principle are given in the document RD4.

The working grid which is used in this algorithm is in geomagnetic latitude and geographic longitude.

From equations (1), (2) and (3), the following matrix system is formed:

$$Z = BX \tag{4}$$

where

Z is the m vector of the weighted measurements
X is the p vector of TEC values at the grid points
B is the m*p matrix which coefficients are computed as follows :

$B_{nk} = c_1 k_1 w_n \alpha_k$ if the grid point k is involved in the interpolation of the points surrounding the subionospheric point 1n
$B_{nk} = -c_1 k_2 w_n \beta_k$ if the grid point k is involved in the interpolation of the points surrounding the subionospheric point 2n
$B_{nk} = 0$ otherwise

The weights of the Doris measurements w_n are introduced through a preconditioning of the matrix B of the linear system.

For each measurement n, non zero coefficients of matrix B are computed. A QR decomposition of matrix B is then performed, applying Givens rotations to matrix B.
Then the system will be solved using a Least Square method.

ALGORITHM SPECIFICATION

The processing is performed for each Doris measurement from the whole data set. The measurement is of type ascending or descending and the matrix R, the right hand side T and the quality index S corresponding to the type of the measurement are updated by the processing.

Warning

- The computation of Doris measurements from Doris level 1.0 parameters
- The computation of the first longitude for the two working grids
- The computation of the parameter to link Doris measurements and the TEC values
- The computation of the number of points of the working grid

are considered as part of "data management and control algorithms". They are specified in the document RD1.

Input data

- Parameter to link Doris measurement and the TEC values : Par_dor_TEC (m /s / 0.1 TECU)
- Degree of interpolation along latitude : Int_deg_lat (/)
- Degree of interpolation along longitude : Int_deg_lon (/)
- Offset on the limits of the working grid in longitude : Offset_lon_wk_grid (degrees)
- Flag on the measurement after final editing : Final_edit_flag (1)
- Doris measurement : Dor_mes (m/s)

- Latitude of subionospheric point at the beginning of the counting period : Lat_sub_bgn(degrees)
- Longitude of subionospheric point at the beginning of the counting period : Lon_sub_bgn(degrees)
- Latitude of subionospheric point at the end of the counting period : Lat_sub_end (degrees)
- Longitude of subionospheric point at the end of the counting period : Lon_sub_end (degrees)
- Conversion coefficient between vertical TEC and slant TEC at the beginning of the counting period : K_bgn (/)
- Conversion coefficient between vertical TEC and slant TEC at the end of the counting period : K_end (/)
- Weight of the measurement : Weight (/)

(1) 2 states: "valid" or "invalid"

- Number of points of the working grid of kind Type, Type = asc and desc : Nb_Type (/)
- Matrix R containing information for the measurement of kind Type
  : R_Type[0:Nb_Type*(Nb_Type+1)/2 - 1] (m /s/ 0.1 TECU)
- Right hand side T containing information for the measurement of kind Type
  : T_Type[0:Nb_Type-1] (m/s)
- Quality index of the LS method for the measurement of kind Type : S_Type (m^2 /s^2)

- Features of the working grids of kind Type, Type = asc and desc
  - Latitude min of the working grid : First_lat_wk_Type (degrees)
  - Number of latitude of the working grid : Nb_lat_wk_Type (/)
  - Latitude step of the working grid : Step_lat_wk_Type (degrees)
  - Longitude min of the working grid : First_lon_wk_Type (degrees)
  - Number of longitude of the working grid : Nb_lon_wk_Type (/)
  - Longitude step of the working grid : Step_lon_wk_Type (degrees)

- Features of the grid of Dip values :
  - Number of grid points in the longitude axis : Nb_lon_dip (/)
  - Number of grid points in the latitude axis : Nb_lat_dip (/)
  - Grid step in the longitude axis : Lon_step_dip (degrees)
  - Grid step in the latitude axis : Lat_step_dip (degrees)
  - First tabulated latitude value : Lon_first_dip (degrees)
  - First tabulated longitude value : Lat_first_dip (degrees)
- Table of Dip values : Tab_dip[0:Nb_lon_dip-1][0:Nb_lat_dip-1] (radians)

Output data

- Flag on the measurement used for the TEC estimation : Estim_val_flag [1]
- Matrix R updated containing information for the measurement of kind Type
  : R_Type[0:Nb_Type*(Nb_Type+1)/2 - 1] (m /s/ 0.1 TECU)
- Right hand side T updated containing information for the measurement of kind Type
  : T_Type[0:Nb_Type-1] (m/s)
- Quality index of the LS method updated for the measurement of kind Type
  : S_Type (m^2 /s^2)
- Geomagnetic latitude of the subionospheric point at the beginning of the counting period
  : Lat_sub_mag_bgn (degrees)

---

[1] 2 states: "valid" or "invalid"

- Geomagnetic latitude of the subionospheric point at the end of the counting period
  : Lat_sub_mag_end (degrees)

Processing

The algorithm presented hereafter is specified for each Doris measurement from the whole data set such that Final_edit_flag is "valid". If Final_edit_flag is "invalid" then the output flag Estim_val_flag is set to "invalid" and the outputs R_Type, T_Type and S_Type are not updated.

- The flag Estim_val_flag is initialized to "invalid"
- Processing of the measurement which belongs to a pass of type ascending or descending :
  - The following process is performed for the subionospheric point at the beginning of the counting period
    - Step 1 (Conversion into geomagnetic latitude)

      To convert geographic latitude of the subionospheric point at the beginning of the counting period into geomagnetic latitude (Lat_sub_mag_bgn) using mechanism "GEN_MEC_CON_05 - Conversion between geographic and geomagnetic latitude" with the following inputs:

      Lat_sub_bgn, Lon_sub_bgn[0:Nb_lon_dip-1][0:Nb_lat_dip-1],Nb_lon_dip, Nb_lat_dip, Lon_step_dip, Lat_step_dip, Lon_first_dip, Lat_first_dip, Tab_dip[0:Nb_lon_dip-1][0:Nb_lat_dip-1]

      If the output flag Flag_grid is "invalid" then the following steps are not performed, the outputs R_Type, T_Type, S_Type are not updated.

    - Step 2 (Computation of the interpolation coefficients)

      To convert the geomagnetic latitude (Lat_sub_mag_bgn) into degrees by multipying by 180/Pi

      To compute interpolation coefficients for the subionospheric point (Lat_sub_mag_bgn, Lon_sub_bgn) at the beginning of the counting period, on the working grid of kind Type, using mechanism "GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid" with the following inputs:

      Int_deg_lat, Int_deg_lon, Lat_sub_mag_bgn, Lon_sub_bgn, Offset_lon_wk_grid, First_lat_wk_Type, Step_lat_wk_Type, Nb_lat_wk_Type, First_lon_wk_Type, Step_lon_wk_Type, Nb_lon_wk_Type.

      Results are the indexes minimum and maximum (Ind_min_bgn, Ind_max_bgn) of the grid points used in the interpolation, the coefficients of interpolation (Alpha(k), k∈[Ind_min_bgn, Ind_max_bgn]) and an output flag (Flag_interp_bgn).
  - The same processing (Step 1 and 2) is applied for the subionospheric point at the end of the counting period, computing the following outputs :

    Lat_sub_mag_end, Ind_min_end, Ind_max_end, Beta(k) with k∈[Ind_min_end, Ind_max_end] and Flag_interp_end
  - If Flag_interp_bgn is "valid" and Flag_interp_end is "valid" then compute row n of matrix B
    - To compute the first indexes to form matrix B

      If Ind_min_bgn< Ind_min_end then Ind_min = Ind_min_bgn

Else Ind_min = Ind_min_end

* To compute the last indexes to form matrix B

  If Ind_max_bgn< Ind_max_end then Ind_max = Ind_max_end

  Else Ind_max = Ind_max_bgn

* To form the row of matrix B, corresponding to the measurement
  - ◊ The row has to be initialized to zero before : B(j) = 0 for $j \in [0, Nb\_Type-1]$
  - ◊ B(j) = Par_dor_TEC * Weight * [K_bgn * Alpha(j) – K_end * Beta(j)]

With $j \in$ [Ind_min, Ind_max]

* The flag Estim_val_flag is set to “valid”.

– Else the flag Estim_val_flag remains to “invalid” and the following step is not performed, the outputs R_Type, T_Type, S_Type are not updated.

• To update the matrix R_Type, the right hand side T_Type and the quality index S_Type

  For a measurement of kind Type, update R_Type, T_Type and S_Type with row n of matrix B and weighted measurement applying a Givens rotation, using mechanism “GEN_MEC_MAT_01 - Updating a QR decomposition using Givens rotation” with the following inputs :

  Nb_Type, B[0:Nb_type-1], Ind_min, Weight*Dor_mes, R_Type, T_Type, S_Type

ACCURACY

N/A

COMMENTS

The TECU is the TEC Unit and 1 TECU = 10^{16} electrons/m^2

REFERENCES

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LOS_ION_TEC_02 - To insure TEC continuity

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
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HERITAGE

TOPEX-POSEIDON

FUNCTION

To insure continuity of TEC values on each working grid (ascending and descending) and continuity between the two grids.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data: none
- Computed data :
  - From "LOS_ION_TEC_01 - To establish the linear system for the computation of TEC on the grid in geomagnetic latitude "
    - Matrixes containing information of the ascending and descending measurements
    - Right hand sides containing information of the ascending and descending measurements
    - Quality indexes of the LS method for the ascending and descending measurements
  - From " LOS_ION_QUA_02 - To compute quality parameters of the Doris measurements"
    - Standard deviation of the adjustment over the whole data set
- Dynamic auxiliary data:
  - Doris orbit data
- Static auxiliary data:
  - Processing parameters
    - Choice between the two methods of continuity processing for interior points
    - Constant term for continuity weighting
    - Constant term for weighting of ascending-descending continuity
    - Continuity weights function of latitude
    - First limit in latitude for the attribution of the continuity weights
    - Second limit in latitude for the attribution of the continuity weights
    - Degree of interpolation along latitude
    - Degree of interpolation along longitude
    - Offset on the limits of the working grid in longitude

  * Features of the ascending and descending working grids
  * Maximal latitude of the satellite
- Dip data

Output data

- Number of pseudo measurements introduced for continuity
- Matrix of the system with continuity constraints
- Right hand side of the system with continuity constraints
- Quality index of the LS method with continuity constraints

Mathematical statement

Continuity of TEC values on the two working grids is insured by applying constraints in the Least Square sense. These constraints are of two kinds :

- to prevent model from divergence in areas of the grid where there are few Doris data, slope breaks are limited in every point of the grid by introducing pseudo measurements which features are :
  - At boundaries of the grid (maximum of latitude and longitude), TEC slope in latitude and longitude is constrained to zero in the Least Square sense.
  - For interior points of the grid, the following choice is possible :
    * Either TEC slope in latitude and longitude is constrained to zero in the Least Square sense (which means the TEC values are constant on the working grid)
    * Either the difference of TEC slope in latitude and longitude is constrained to zero in the Least Square sense (which means the TEC derivatives are constant on the working grid)
- to respect physics of ionosphere, continuity of TEC values at extreme latitudes of the satellite is insured (the TEC values at these latitudes between the ascending and descending grids are equal)

Constraints of kind 1 : continuity at grid points

A weight is calculated for each pseudo measurement. For the grid point (i,j) processed to insure continuity, the weight is computed according to the following way:

$$\text{Weight}(i, j) = \frac{1}{\text{Cst\_cont}} \frac{1}{\text{Std\_qual\_glob}} \frac{1}{\text{Weight\_cont}} \quad (1)$$

- The value Cst_cont is fixed in the processing parameters.
- Std_qual_glob is the standard deviation of the adjustment over the whole data set issued from "LOS_ION_QUA_02 - To compute quality parameters of the Doris measurements"
- Weight_cont is a weight, function of :
  - the type of continuity applied: latitude or longitude continuity

– the latitude i of the point (i,j) of the grid

This weight is a standard deviation value determined by a study of slope difference of TEC computed with Topex data in each point of the grid. The result of this study shows that the grid can be divided into 3 parts, function of latitude and a standard deviation value is associated to each part.
Latitudes are sorted according to the following classification :

Abs(lat) < 25°, 25° ≤ Abs(lat) ≤ 55°, Abs(lat) > 55°.

Ascending and descending measurements are processed separately : pseudo measurements are introduced on the two working grids. They are taken into account in matrixes and vectors R_desc, T_desc and R_asc, T_asc.

These matrix and vectors are recomposed in the end to form the matrix and right hand side of the system R_tot and T_tot.

Constraints of kind 2 : continuity between the two grids

The pseudo measurements introduced at the extreme latitudes of the satellite are weighted with a constant weight calculated according to the following way :

$$\text{Weight} = \frac{1}{\text{Cst\_cont}}\,\frac{1}{\text{Std\_qual\_glob}}\,\frac{1}{\text{Cont\_pol}} \qquad (2)$$

where Cst_cont and Cont_pol are constants fixed in the processing parameters.

The processing is performed using the global matrix of the system R_tot and T_tot.
The ascending and descending grids are computed by a data management algorithm. The longitudes of the grids have been translated of k*360° to cover two days on a continuous scale and to take into account the prograd or retrograd orbit. Thus, before applying continuity equation between both grids, some management has to be done to select the shared grid points.

Further details about the equations of continuity are given in the document RD4.

ALGORITHM SPECIFICATION

The processing is performed for the ascending working grid and the descending working grid. It is described hereafter for the generic term y, y = asc and desc.

Warning

- The computation of the first longitude for the two working grids
- The computation of the number of grid points for the working grids

are considered as part of “data management and control algorithms”. Thus, they are specified in the document RD1.

Input data

- Choice between the two methods of continuity processing for interior points : Option_cont [(1)]
- Constant term for continuity weighting : Cst_cont (/)
- Constant term for weighting of ascending-descending continuity : Cont_pol (/)
- Continuity weights function of latitude : Weight_cont [0:2] [0:1] (/)
- First limit in latitude for the attribution of the continuity weights : First_lim_lat_cont (degrees)
- Second limit in latitude for the attribution of the continuity weights : Second_lim_lat_cont (degrees)
- Degree of interpolation versus latitude : Int_deg_lat (/)
- Degree of interpolation versus longitude : Int_deg_lon (/)
- Offset on the limits of the working grid in longitude : Offset_lon_wk_grid (degrees)
- Standard deviation of the adjustment over the whole data set : Std_qual_glob (m/s)
- Maximal latitude of the satellite : Lat_sat_max (degrees)
- Nature of the orbit (depending on the processed mission) : Orbit_pro_ret [(2)]

- Number of points of the working grid of kind y : Nb_y (/)
- Number of points of the two working grids : Nb (/)
- Matrix containing information of the measurements of kind y : R_y[0:Nb_y*(Nb_y+1)/2 - 1] (m /s / 0.1 TECU)
- Right hand side containing information of the measurements of kind y : T_y[0:Nb_y-1] (m/s)
- Quality index of the LS method for the measurements of kind y : S_y (m^2/s^2)
- Features of the working grid of kind y
  - Latitude min of the working grid : First_lat_wk_y (degrees)
  - Number of latitude of the working grid : Nb_lat_wk_y (/)
  - Latitude step of the working grid : Step_lat_wk_y (degrees)
  - Longitude min of the working grid : First_lon_wk_y (degrees)
  - Number of longitude of the working grid : Nb_lon_wk_y (/)
  - Longitude step of the working grid : Step_lon_wk_y (degrees)
- Features of the grid of Dip values :

---

(1) 2 states: 0 if the TEC slope is constrained to zero
1 if the difference of TEC slope is constrained to zero

(2) 2 states: 0 if the orbit is prograd
1 if the orbit is retrograd

- Number of grid points in the longitude axis : Nb_lon_dip (/)
- Number of grid points in the latitude axis : Nb_lat_dip (/)
- Grid step in the longitude axis : Lon_step_dip (degrees)
- Grid step in the latitude axis : Lat_step_dip (degrees)
- First tabulated latitude value : Lon_first_dip (degrees)
- First tabulated longitude value : Lat_first_dip (degrees)

- Table of Dip values : : Tab_dip[0:Nb_lon_dip-1][0:Nb_lat_dip-1] (radians)

Output data

- Number of pseudo measurements introduced for continuity : Nb_pseudo_mes (/)
- Matrix of the system with continuity constraints
  : R_tot[0:Nb*(Nb+1)/2 - 1] (m /s / 0.1 TECU)
- Right hand side with continuity constraints : T_tot[0:Nb-1] (m/s)
- Quality index of the LS method with continuity constraints : S_tot (m^2 /s^2)

Processing

Nb_pseudo_mes=0

Continuity at grid points

- Continuity in latitude
  - For interior points of the grid located by (i,j) :

    The interior points are processed for i ∈ [1, Nb_lat_wk_y -2] and j ∈ [0, Nb_lon_wk_y -1]

    - To compute latitude of grid point (i,j):

      Latitude = First_lat_wk_y + i * Step_lat_wk_y (1)

    - To compute the weight at grid point (i,j) (Weight) :

      Weight = 1/Cst_cont * 1/Std_qual_glob * 1/W_cont * 180 / pi (2)

      The value of W_cont is determined according to latitude of the point Latitude (first index of the array Weight_cont) and for continuity in latitude (second index of the array Weight_cont set to zero for latitude) :

      If (| Latitude | < First_lim_lat_cont) then W_cont = Weight_cont(0) (0)

      If (| Latitude | > Second_lim_lat_cont) then W_cont = Weight_cont(2) (0)

      Else (First_lim_lat_cont ≤ | Latitude | ≤ Second_lim_lat_cont)

      then W_cont = Weight_cont(1) (0)

    - To form row of matrix B corresponding to the pseudo measurement
      - ◊ To initialize the row of matrix B

B(k) = 0 for k = 0, Nb_y-1

◊ Translation of indexes is processed to get the global index k associated to the grid point (i,j) using the following formula :

$$k = i * Nb\_lon\_wk\_y + j \quad (3)$$

This formula is valid for a numeration of the grid by increasing longitude.

◊ If Option_cont is such that TEC values are constant, row of matrix B is computed by:

$$B(k) = Weight / Step\_lat\_wk\_y \quad (4)$$

$$B(k - Nb\_lon\_wk\_y) = -Weight / Step\_lat\_wk\_y \quad (5)$$

◊ If Option_cont is such that TEC derivatives are constant, row of matrix B is computed by:

$$B(k) = -2 * Weight / Step\_lat\_wk\_y \quad (6)$$

$$B(k - Nb\_lon\_wk\_y) = Weight / Step\_lat\_wk\_y \quad (7)$$

$$B(k + Nb\_lon\_wk\_y) = Weight / Step\_lat\_wk\_y \quad (8)$$

* To form the matrix R_y, the right hand side T_y and the quality index S_y

  For a grid of kind y, update R_y, T_y and S_y with row of matrix B and right hand side set to zero, applying a Givens rotation, using mechanism “GEN_MEC_MAT_01 - Updating a QR decomposition using Givens rotation” with the following inputs :
  Nb_y, B[0:Nb_y-1], Ind_min = k- Nb_lon_wk_y, 0, R_y, T_y, S_y.

* The number of pseudo measurements introduced for continuity (Nb_pseudo_mes) is incremented

– For extreme latitudes of the grid, TEC continuity is insured for all longitudes j ∈ [0, Nb_lon_wk_y-1] :

* For the first latitude i = 0

  ◊ Latitude = First_lat_wk_y

  ◊ To initialize the row of matrix B

  B(k) = 0 for k = 0, Nb_y-1

  ◊ To compute the weight at grid point (i,j) (Weight) :

$$Weight = 1/Cst\_cont * 1/Std\_qual\_glob * 1/W\_cont * 180 / pi \quad (9)$$

  The value of W_cont is determined according to the latitude of the point Latitude and for continuity in latitude.

  If (| Latitude | < First_lim_lat_cont) then W_cont = Weight_cont(0) (0)

  If (| Latitude | > Second_lim_lat_cont) then W_cont = Weight_cont(2) (0)

  Else (First_lim_lat_cont ≤ | Latitude | ≤ Second_lim_lat_cont)

  then W_cont = Weight_cont(1) (0)

$$B(j) = -Weight / Step\_lat\_wk\_y \quad (10)$$

$$B(j + Nb\_lon\_wk\_y) = Weight / Step\_lat\_wk\_y \quad (11)$$

◊ To form the matrix R_y, the right hand side T_y and the quality index S_y

For a grid of kind y, update R_y, T_y and S_y with row of matrix B and right hand side set to zero, applying a Givens rotation, using mechanism "GEN_MEC_MAT_01 - Updating a QR decomposition using Givens rotation" with the following inputs :
Nb_y, B[0:Nb_y-1], Ind_min = j , 0, R_y, T_y, S_y.

◊ The number of pseudo measurements introduced for continuity (Nb_pseudo_mes) is incremented

∗ For the last latitude i = Nb_lat_wk_y –1

◊ Latitude = First_lat_wk_y + (Nb_lat_wk_y –1)* Step_lat_wk_y

◊ To initialize the row of matrix B

B(k) = 0 for k = 0, Nb_y -1

◊ To compute the weight at grid point (i,j) (Weight) :

Weight = 1/Cst_cont * 1/Std_qual_glob * 1/W_cont * 180 / pi (12)

The value of W_cont is determined according to latitude of the point Latitude and for continuity in latitude.

If (| Latitude | < First_lim_lat_cont) then W_cont = Weight_cont(0) (0)

If (| Latitude | > Second_lim_lat_cont) then W_cont = Weight_cont(2) (0)

Else (First_lim_lat_cont ≤ | Latitude | ≤ Second_lim_lat_cont)

then W_cont = Weight_cont(1) (0)

k = (Nb_lat_wk_y-2) * Nb_lon_wk_y + j (13)

B(k) = -Weight / Step_lat_wk_y (14)

B(k + Nb_lon_wk_y) = Weight / Step_lat_wk_y (15)

◊ To form the matrix R_y, the right hand side T_y and the quality index S_y

For a grid of kind y, update R_y, T_y and S_y with row of matrix B and right hand side set to zero, applying a Givens rotation, using mechanism "GEN_MEC_MAT_01 - Updating a QR decomposition using Givens rotation" with the following inputs :
Nb_y, B[0:Nb_y-1], Ind_min = k , 0, R_y, T_y, S_y.

◊ The number of pseudo measurements introduced for continuity (Nb_pseudo_mes) is incremented

- Continuity in longitude
  - For interior points of the grid located by (i,j) :

    The interior points are processed for $i \in [0, Nb\_lat\_wk\_y -1]$ and $j \in [1, Nb\_lon\_wk\_y -2]$

    - To compute latitude of grid point (i,j) :

      $$Latitude = First\_lat\_wk\_y + i*Step\_lat\_wk\_y \quad (16)$$

    - To compute the weight at grid point (i,j) (Weight) :

      $$Weight = 1/Cst\_cont * 1/Std\_qual\_glob * 1/W\_cont * 180 / pi \quad (17)$$

      The value of W_cont is determined according to latitude of the point Latitude and for continuity in longitude (second index of the array Weight_cont set to 1 for longitude).

      If (| Latitude | < First_lim_lat_cont) then W_cont = Weight_cont(0) (1)

      If (| Latitude | > Second_lim_lat_cont) then W_cont = Weight_cont(2) (1)

      Else (First_lim_lat_cont ≤ | Latitude | ≤ Second_lim_lat_cont)

      then W_cont = Weight_cont(1) (1)

    - To form row of matrix B corresponding to the pseudo measurement
      - ◊ To initialize the row of matrix B

        B(k) = 0 for k = 0, Nb_y -1
      - ◊ Translation of indexes is processed to get the global index k associated to the grid point (i,j) using the formula (3)
      - ◊ If Option_cont is such that TEC values are constant, row of matrix B is computed by :

        $$B(k) = Weight / Step\_lon\_wk\_y \quad (18)$$

        $$B(k-1) = -Weight / Step\_lon\_wk\_y \quad (19)$$
      - ◊ If Option_cont is such that TEC derivatives are constant, row of matrix B is computed by :

        $$B(k) = -2 * Weight / Step\_lon\_wk\_y \quad (20)$$

        $$B(k-1) = Weight / Step\_lon\_wk\_y \quad (21)$$

        $$B(k+1) = Weight / Step\_lon\_wk\_y \quad (22)$$

    - To form the matrix R_y, the right hand side T_y and the quality index S_y

      For a grid of kind y, update R_y, T_y and S_y with row of matrix B and right hand side set to zero, applying a Givens rotation, using mechanism "GEN_MEC_MAT_01 - Updating a QR decomposition using Givens rotation" with the following inputs :
      Nb_y, B[0:Nb_y-1], Ind_min = k-1 , 0, R_y, T_y, S_y.

    - The number of pseudo measurements introduced for continuity (Nb_pseudo_mes) is incremented

  - For extreme longitudes of the grid, TEC continuity is insured for all latitudes $i \in [0, Nb\_lat\_wk\_y-1]$:
    - For the first longitude j = 0

◊ To initialize the row of matrix B

B(k) = 0 for k = 0, Nb_y -1

◊ Latitude = First_lat_wk_y + i*Step_lat_wk_y

◊ To compute the weight at grid point (i,j) (Weight) :

Weight = 1/Cst_cont * 1/Std_qual_glob * 1/W_cont * 180 / pi (23)

The value of W_cont is determined according to latitude of the point Latitude and for continuity in longitude:

If (| Latitude | < First_lim_lat_cont) then W_cont = Weight_cont(0) (1)

If (| Latitude | > Second_lim_lat_cont) then W_cont = Weight_cont(2) (1)

Else (First_lim_lat_cont ≤ | Latitude | ≤ Second_lim_lat_cont)

then W_cont = Weight_cont(1) (1)

k = i * Nb_lon_wk_y (24)

B(k) = -Weight / Step_lon_wk_y (25)

B(k +1) = Weight / Step_lon_wk_y (26)

◊ To form the matrix R_y, the right hand side T_y and the index quality S_y

For a grid of kind y, update R_y, T_y and S_y with row of matrix B and right hand side set to zero, applying a Givens rotation, using mechanism "GEN_MEC_MAT_01 - Updating a QR decomposition using Givens rotation" with the following inputs :
Nb_y, B[0:Nb_y-1], Ind_min = k , 0, R_y, T_y, S_y.

◊ The number of pseudo measurements introduced for continuity (Nb_pseudo_mes) is incremented

* For the last longitude j = Nb_lon_wk_y-1

◊ To initialize the row of matrix B

B(k) = 0 for k = 0, Nb_y -1

◊ Latitude = First_lat_wk_y + i*Step_lat_wk_y

◊ To compute the weight at grid point (i,j) (Weight) :

Weight = 1/Cst_cont * 1/Std_qual_glob * 1/W_cont * 180 / pi (27)

The value of W_cont is determined according to latitude of the point Latitude and for continuity in longitude :

If (| Latitude | < First_lim_lat_cont) then W_cont = Weight_cont(0) (1)

If (| Latitude | > Second_lim_lat_cont) then W_cont = Weight_cont(2) (1)

Else (First_lim_lat_cont ≤ | Latitude | ≤ Second_lim_lat_cont)

then W_cont = Weight_cont(1) (1)

k = (i+1) * Nb_lon_wk_y-1 (28)

B(k) = Weight / Step_lon_wk_y (29)

B(k-1) = -Weight / Step_lon_wk_y (30)

◊ To form the matrix R_y, the right hand side T_y and the quality index S_y

For a grid of kind y, update R_y, T_y and S_y with row of matrix B and right hand side set to zero, applying a Givens rotation, using mechanism “GEN_MEC_MAT_01 - Updating a QR decomposition using Givens rotation” with the following inputs :
Nb_y, B[0:Nb_y-1], Ind_min = k-1 , 0, R_y, T_y, S_y.

◊ The number of pseudo measurements introduced for continuity (Nb_pseudo_mes) is incremented

- To form matrix R_tot, right hand side T_tot and the quality index S_tot of the processing
  - To calculate the quality index of the LS method with the ascending value and descending value

$$S\_tot = S\_asc + S\_desc \quad (31)$$

  - To form right hand side T_tot with ascending values and descending values:

$$T\_tot(k) = T\_desc(k) \qquad \text{with } k \in [0, Nb\_desc - 1] \quad (32)$$

$$T\_tot(k + Nb\_desc) = T\_asc(k) \qquad \text{with } k \in [0, Nb\_asc - 1] \quad (33)$$

  - To form matrix R_tot

R_tot is a triangular matrix stored in a one dimension array. R_tot must be formed respecting the storage of T_tot.

Thus each row of matrix R_desc is stored in R_tot with the Nb_asc successive coefficients of R_tot set to zero. The matrix R_asc is stored in the end of R_tot, in the initial order of R_asc.

R_tot = [row 1 of R_desc (Nb_desc values), 0…0 (Nb_asc zeros),

row 2 of R_desc (Nb_desc-1 values) , 0…0 (Nb_asc zeros),

row 3 of R_desc (Nb_desc-2 values) , 0…0 (Nb_asc zeros),

…………

row Nb_desc of R_desc (1 value) , 0…0 (Nb_asc zeros),

row 1 of R_asc (Nb_asc values) ,

row 2 of R_asc (Nb_asc-1 values) ,

…………

row Nb_asc of R_asc (1 value)] (34)

Continuity between ascending and descending grids

The following processing is performed for the two extreme latitudes of the satellite (Lat_sat_min = - Lat_sat_max and Lat_sat_max = + Lat_sat_max). It is described in the following algorithm for Lat_sat_x, with x = min, max.

For all the longitudes of the ascending working grid (Lon_asc), to determine if this longitude exists in the descending working grid.

Last_lon_wk_desc = First_lon_wk_desc + (Nb_lon_wk_desc-1) * Step_lon_wk_desc

$$Lon\_asc = First\_lon\_wk\_asc + j*Step\_lon\_wk\_asc, \qquad j \in [0,Nb\_lon\_wk\_asc-1] \tag{35}$$

- The test on Lon_asc is performed by the following steps :
  - If (First_lon_wk_desc > First_lon_wk_asc) then

    Mult = 2
    - ∗ If the orbit is prograd then the longitudes are increasing
      - ◊ If (Lat_sat_x = Lat_sat_min) then

        If (First_lon_wk_desc ≤ Lon_asc+360 ≤ Last_lon_wk_desc

        Then Mult = 1
      - ◊ Else (Lat_sat_x = Lat_sat_max) then

        If (First_lon_wk_desc ≤ Lon_asc ≤ Last_lon_wk_desc

        Then Mult = 0
    - ∗ If the orbit is retrograd then the longitudes are decreasing
      - ◊ If (Lat_sat_x = Lat_sat_min) then

        If (First_lon_wk_desc ≤ Lon_asc≤ Last_lon_wk_desc

        Then Mult = 0
      - ◊ Else (Lat_sat_x = Lat_sat_max) then

        If (First_lon_wk_desc ≤ Lon_asc+360 ≤ Last_lon_wk_desc

        Then Mult = 1
  - Else

    Mult = 2
    - ∗ If the orbit is prograd then the longitudes are increasing
      - ◊ If (Lat_sat_x = Lat_sat_min) then

        If (First_lon_wk_desc ≤ Lon_asc ≤ Last_lon_wk_desc

        Then Mult = 0
      - ◊ Else (Lat_sat_x = Lat_sat_max) then

        If (First_lon_wk_desc ≤ Lon_asc - 360 ≤ Last_lon_wk_desc

        Then Mult = -1
    - ∗ If the orbit is retrograd then the longitudes are decreasing

◊ If (Lat_sat_x = Lat_sat_min) then

If (First_lon_wk_desc ≤ Lon_asc - 360 ≤ Last_lon_wk_desc

Then Mult = -1

◊ Else (Lat_sat_x = Lat_sat_max) then

If (First_lon_wk_desc ≤ Lon_asc ≤ Last_lon_wk_desc

Then Mult = 0

- If (| Mult | = 2) then the longitude (Lon_asc) is not in the descending working grid and TEC continuity cannot be assured for this point. The following longitude is processed.
- Else (| Mult | ≤ 1) then the longitude (Lon_asc) exists in the descending working grid and the row of matrix B is computed by :

– To compute the weight of the pseudo measurement

Weight = 1/Cst_cont * 1/Cont_pol * 1/Std_qual_glob (36)

– To convert geographic latitude of the satellite into geomagnetic latitude (Lat_sat_x_mag) using mechanism "GEN_MEC_CON_05 - Conversion between geographic and geomagnetic latitude" with the following inputs:

Lat_sat_x (in degrees), Lon_asc (in degrees) and Dip data

If the output flag Flag_grid is "invalid" then the following steps are not performed and the outputs R_tot, T_tot, S_tot and Nb_pseudo_mes are not updated. The following longitude (Lon_asc) is then processed.

– To initialize the array of the coefficients of interpolation (outputs of mechanism "GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid") :

Coeff_asc(k) = 0 for k = 0,Nb-1 (37)

Coeff_desc(k) = 0 for k= 0,Nb-1 (38)

– To compute interpolation coefficients for the point (Lat_sat_x_mag, Lon_asc), on the ascending working grid, using mechanism "GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid" with the following inputs :

The input Lat_sat_x_mag (radians) must be converted in degrees.

Int_deg_lat, Int_deg_lon, Lat_sat_x_mag, Lon_asc, Offset_lon_wk_grid, First_lat_wk_asc, Step_lat_wk_asc, Nb_lat_wk_asc, First_lon_wk_asc, Step_lon_wk_asc, Nb_lon_wk_asc

Results are indexes minimum and maximum (Ind_min_asc, Ind_max_asc) of grid points used in the interpolation, coefficients of interpolation (Coeff_asc[Ind_min_asc, Ind_max_asc]) and an output flag (Flag_interp_1).

– To translate the longitude Lon_asc :

Lon_asc_trans = Lon_asc + Mult * 360 (39)

– To compute interpolation coefficients for the point (Lat_sat_x_mag, Lon_asc_trans) on the descending working grid, using mechanism " GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid" with the following inputs :

The input Lat_sat_x_mag (radians) must be converted in degrees.

Int_deg_lat, Int_deg_lon, Lat_sat_x_mag, Lon_asc_trans, First_lat_wk_desc, Step_lat_wk_desc, Nb_lat_wk_desc, First_lon_wk_desc, Step_lon_wk_desc, Nb_lon_wk_desc

Results are indexes minimum and maximum (Ind_min_desc, Ind_max_desc) of grid points used in the interpolation, coefficients of interpolation (Coeff_desc[Ind_min_desc, Ind_max_desc]) and an output flag (Flag_interp_2).

- If Flag_interp1 is "valid" and Flag_interp2 is "valid" then compute row of matrix B
  - To initialize the row of matrix B

    B(k) = 0 for k = 0, Nb-1 (40)
  - To translate the values of Coeff_asc :

    For i = Ind_min_asc, Ind_max_asc

    Coeff_asc(i + Nb_desc) = Coeff_asc(i) (41)

    Coeff_asc(i) = 0 (42)

    Ind_min_asc = Ind_min_asc + Nb_desc (43)

    Ind_max_asc = Ind_max_asc + Nb_desc (44)
  - To compute the first indexes to form matrix B

    If Ind_min_asc < Ind_min_desc then Ind_min = Ind_min_asc (45)

    Else Ind_min = Ind_min_desc (46)
  - To compute the last indexes to form matrix B

    If Ind_max_asc < Ind_max_desc then Ind_max = Ind_max_desc (47)

    Else Ind_max = Ind_max_asc (48)
  - To form row of matrix B

    B(k) = Weight * [Coeff_desc(k) – Coeff_asc(k)] with $k \in [\text{Ind\_min}, \text{Ind\_max}]$ (49)

- To update the matrix R_tot, the right hand side T_tot and S_tot with row of matrix B and right hand side set to zero applying a Givens rotation, using mechanism "GEN_MEC_MAT_01 - Updating a QR decomposition using Givens rotation" with the following inputs :

  Nb, B[0:Nb-1], Ind_min, 0, R_tot, T_tot, S_tot
- The number of pseudo measurements introduced for continuity (Nb_pseudo_mes) is incremented

ACCURACY

N/A

COMMENTS

- The value for the constant term Cst_cont will be settled during the verification phase.
- The TECU is the TEC Unit and 1 TECU = 10^{16} electrons/m^2

REFERENCES

None

Affaires Techniques Projets et Services Opérationnels
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31401 TOULOUSE CEDEX 4

LOS_ION_TEC_03 - To compute TEC values on the grid in geomagnetic latitude

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
Checked by:	N. PICOT	
Approved by:	P. VINCENT	

Document ref:	SMM-SP-M2-EA-11013-CN	18th October, 2001	Issue: 1	Update: 1

Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To compute TEC values on the two working grids (ascending and descending) in geomagnetic latitude, geographic longitude by solving the system.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data: none
- Computed data :
  - From "LOS_ION_TEC_02 - To insure TEC continuity"
    - Matrix issued from QR decomposition with continuity constraints
    - Right hand side issued from QR decomposition with continuity constraints
- Dynamic auxiliary data: none
- Static auxiliary data:
  - Processing parameters
    - Number of working grid points for both grids

Output data

- TEC values at ascending working grid points
- TEC values at descending working grid points

Mathematical statement

After QR decomposition, the system BX = Z is reduced to the triangular system RX = T, which is much more easier to s
The TEC values (vector X) are then estimated on the working grids (in the geomagnetic reference).

ALGORITHM SPECIFICATION

Input data

Number of working grid points for both grids : Nb (/)

Triangular matrix with continuity constraints
: R_tot[0:Nb*(Nb+1)/2 - 1] (m /s / 0.1 TECU)
Right hand side with continuity constraints : T_tot[0:Nb-1] (m/s)

Output data

TEC values at working grid points for descending and ascending grids : X[0:Nb-1] (0.1TECU)
TEC values for the descending grid are stored in X[0:Nb_desc-1]
TEC values for the ascending grid are stored in X[Nb_desc:Nb-1]

Processing

Processing is reduced to the following statement:

To compute TEC values (X) solving the triangular system : R_tot*X = T_tot

Vector X solution of system R_tot * X = T_tot is computed using routine F06PLF of the NAG Fortran library (RD8).

This function is called with the following arguments:

UPLO	= 'L'	[input]
TRANS	= 'T'	[input]
DIAG	= 'N'	[input]
N	= Nb	[input]
AP	= R_tot (triangular matrix stored in one vector)	[input]
X	= T_tot	[input/output]
INCX	= 1	[input]
LENGTH_1	= 1 (length of the string UPLO)	[input]
LENGTH_2	= 1 (length of the string TRANS)	[input]
LENGTH_3	= 1 (length of the string DIAG)	[input]

The output (the solution X) is stored in the vector T_tot

ACCURACY

The accuracy is linked to the numerical method used to solve the triangular system.

COMMENTS

- TEC estimation is performed on a working grid. The working grid mesh is less precise than one could expected to take into account the geometry of the visibility circles of the network of Doris beacons. Furthermore, it prevents the model from divergence and avoids long computing time.

  Afterwards, TEC values are calculated on a more refined and regular grid (the output grid), using interpolation.

- The TECU is the TEC Unit and 1 TECU = 10^{16} electrons/m^2

REFERENCES

None

Affaires Techniques Projets et Services Opérationnels
Sous-Direction Etudes Systèmes et Développements
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LOS_ION_TEC_04 - To interpolate TEC values on the geographical grid

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	S. LABROUE	
Checked by:	N. PICOT	
Approved by:	P. VINCENT	

Document ref:	SMM-SP-M2-EA-11013-CN	18th October, 2001	Issue: 1	Update: 1

Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

New TEC values on a geographical grid (geographic latitude, longitude) are calculated by interpolation from the TEC values on the working grids.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data: none
- Computed data :
  - From "LOS_ION_TEC_03 - To compute TEC values on the grid in geomagnetic latitude ”
    - TEC values at working grid points for the ascending and descending grids
- Dynamic auxiliary data: none
- Static auxiliary data:
  - Processing parameters
    - Degree of interpolation versus latitude
    - Degree of interpolation versus longitude
    - Offset on the limits of the working grid in longitude
    - Features of the working grids
    - Features of the output grids
    - Number of points of the ascending working grid
    - Number of points of the descending working grid
    - Number of points of the two working grids
  - Dip data

Output data

- TEC values on the ascending output grid in geographic latitude, longitude
- TEC values on the descending output grid in geographic latitude, longitude
- Latitude values on the ascending output grid in geographic latitude, longitude

- Latitude values on the descending output grid in geographic latitude, longitude
- Longitude values on the ascending output grid in geographic latitude, longitude
- Longitude values on the descending output grid in geographic latitude, longitude

Mathematical statement

The aim of the function is to compute the TEC values on the geographical grid, using the TEC values computed on the grid in geomagnetic latitude.

First, a change of referential has to be done : the latitude of the grid points of the geographical grid are converted into geomagnetic latitude. The interpolation of the TEC values is then performed to the location of the geographic grid points once converted into the geomagnetic reference.

TEC value at output grid point i is given by the following equation:

$$TEC_i = \sum_{j \in J} \alpha_j X_j \qquad (1)$$

TEC_i is the TEC value to be determined at point i on the output grid

X_j are the known TEC values at working grid points

J is the set of indexes of the working grid points involved in the interpolation and surrounding the point i

α_j are the coefficients calculated by interpolation

Note that interpolation performed in this function is built on the same principle as interpolation described in mechanism " GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid".

ALGORITHM SPECIFICATION

The following algorithm is processed identically for the ascending output grid and the descending output grid, except for the final computation of TEC value on the output grid.
It is described for a grid of kind y with y = asc and desc in the following processing, the last step being detailed for the ascending and descending grids.

Warning

The computation of the first longitude for the working grids and for the output grids is considered as part of "data management and control algorithms". Thus, it is specified in the document RD1.

Input data

- Degree of interpolation versus latitude : Int_deg_lat (/)
- Degree of interpolation versus longitude : Int_deg_lon (/)

- Offset on the limits of the working grid in longitude : Offset_lon_wk_grid (degrees)
- Number of points in the two working grids : Nb (/)
- Number of points of the working grid of kind y : Nb_y (/)
- TEC values at working grid points : X[0:Nb-1] (0.1 TECU)
- Features of the output grid of kind y :
  - First latitude of the output grid : First_lat_out_y (degrees)
  - Number of latitude of the output grid : Nb_lat_out_y (/)
  - Latitude step of the output grid : Step_lat_out_y (degrees)
  - First longitude of the output grid : First_lon_out_y (degrees)
  - Number of longitude of the output grid : Nb_lon_out_y (/)
  - Longitude step of the output grid : Step_lon_out_y (degrees)
- Features of the working grid of kind y :
  - Latitude min of the working grid : First_lat_wk_y (degrees)
  - Number of latitude of the working grid : Nb_lat_wk_y (/)
  - Latitude step of the working grid : Step_lat_wk_y (degrees)
  - Longitude min of the working grid : First_lon_wk_y (degrees)
  - Number of longitude of the working grid : Nb_lon_wk_y (/)
  - Longitude step of the working grid : Step_lon_wk_y (degrees)
- Features of the grid of Dip values :
  - Number of grid points in the longitude axis : Nb_lon_dip (/)
  - Number of grid points in the latitude axis : Nb_lat_dip (/)
  - Grid step in the longitude axis : Lon_step_dip (degrees)
  - Grid step in the latitude axis : Lat_step_dip (degrees)
  - First tabulated latitude value : Lon_first_dip (degrees)
  - First tabulated longitude value : Lat_first_dip (degrees)
- Table of Dip values : Tab_dip[0:Nb_lon_dip-1][0:Nb_lat_dip-1] (radians)

Output data

- TEC values on the ascending output grid
  : TEC_asc[0:Nb_lat_out_asc-1][0:Nb_lon_out_asc-1] (0.1 TECU)
- TEC values on the descending output grid
  : TEC_desc[0:Nb_lat_out_desc-1][0:Nb_lon_out_desc-1] (0.1 TECU)
- Latitude values on the ascending output grid
  : Lat_asc [0:Nb_lat_out_asc-1][0:Nb_lon_out_asc-1] (degrees)
- Latitude values on the descending output grid
  : Lat_desc [0:Nb_lat_out_desc-1][0:Nb_lon_out_desc-1] (degrees)

- Longitude values on the ascending output grid
  : Lon_asc [0:Nb_lat_out_asc-1][0:Nb_lon_out_asc-1] (degrees)
- Longitude values on the descending output grid
  : Lon_desc [0:Nb_lat_out_desc-1][0:Nb_lon_out_desc-1] (degrees)

Processing

For each point (i,j) of the output grid of kind y (y = asc and desc) :

For i = 0, Nb_lat_out_y-1

For j = 0, Nb_lon_out_y-1

- To compute the latitude and longitude of the grid point (i,j) by :

  Lat_y (i,j) = First_lat_out_y + i * Step_lat_out_y (1)
  Lon_y (i,j) = First_lon_out_y + j * Step_lon_out_y (2)

- To convert geographic latitude of the output grid point into geomagnetic latitude (Lat_mag) using "GEN_MEC_CON_05 - Conversion between geographic and geomagnetic latitude" with the following inputs:

  Lat_y(i,j),Lon_y(i,j),Nb_lon_dip, Nb_lat_dip, Lon_step_dip, Lat_step_dip, Lon_first_dip, Lat_first_dip, Tab_dip[0:Nb_lon_dip-1][0:Nb_lat_dip-1]

  If the output flag Flag_grid is "invalid" then the following steps are not performed and the output TEC_y(i,j) is set to a default value. The following grid point is processed.

- To compute interpolation coefficients :

  To convert the geomagnetic latitude (Lat_mag) into degrees

  To compute interpolation coefficients on the working grid of kind y, using mechanism " GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid" with the following inputs :

  Int_deg_lat, Int_deg_lon, Lat_mag, Lon_y(i,j), Offset_lon_wk_grid, First_lat_wk_y, Step_lat_wk_y, Nb_lat_wk_y, First_lon_wk_y, Step_lon_wk_y, Nb_lon_wk_y

  Results are indexes minimum and maximum (Min, Max) of grid points used in the interpolation, coefficients of interpolation (Alpha(k) with $k \in$ [Min, Max]) and an output flag (Flag_interp).

- If Flag_interp is valid then to interpolate TEC value at grid point (i,j) using equation (1) from the definition section and TEC values on the working grid (X) :
  - If the point (i,j) is a grid point of the descending output grid (y = desc) then :

    $$\mathrm{TEC\_desc}(i,j) = \sum_{k=\min}^{\max} \mathrm{Alpha}(k) * X(k) \tag{3}$$

  - Else the point (i,j) is a grid point of the ascending output grid (y = asc) then :

    For the ascending TEC, special processing must be performed using a translation of indexes k on X because ascending values of TEC are stored in X(k) $k \in [\mathrm{Nb\_desc}, \mathrm{Nb}-1]$. Thus ascending TEC values are computed by:

    $$\mathrm{TEC\_asc}(i,j) = \sum_{k=\min}^{\max} \mathrm{Alpha}(k) * X(k+\mathrm{Nb\_desc}) \tag{4}$$

ACCURACY

N/A

COMMENTS

The TECU is the TEC Unit and 1 TECU = 10^{16} electrons/m^2

REFERENCES

None

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LOS_ION_QUA_04 - To assess the quality of the TEC estimation

DEFINITION, ACCURACY AND SPECIFICATION

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	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To compute the parameters used to assess the quality of the TEC estimation performed.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data: none
- Computed data :
  - From "LOS_ION_TEC_02 - To insure TEC continuity"
    - Matrix of the system with continuity constraints
    - Quality index of the LS method with continuity constraints
    - Number of pseudo measurements introduced for continuity
  - From "LOS_ION_TEC_03 - To compute TEC values on the grid in geomagnetic latitude "
    - TEC values at working grid points for ascending and descending grids
- Dynamic auxiliary data: none
- Static auxiliary data:
  - Processing parameters
    - Features of the working grids
    - Number of points of the two working grids
    - Features of the output grids
    - Degree of interpolation versus latitude
    - Degree of interpolation versus longitude
    - Offset on the limits of the working grid in longitude
    - Weighting constant for the quality index of the LS method
  - Dip data

Output data

- Normalized quality index of the LS method

- Standard deviation of TEC values at working grid points
- Covariance matrix of the system on the working grid
- Covariance on the output grid

Mathematical statement

This function provides parameters for the assessment of the quality of the estimation :

- The normalized quality index of the LS method
- The matrix of covariance
- The standard deviation of the TEC values on the working grids.
- The TEC covariance at each output grid point

Quality index of the LS method

The quality index is the value which has been minimized in the Least Square method and it is expressed by the following equation :

$$S = \sum_{i=p+1}^{m} \theta(i)^2 \tag{1}$$

where $\theta = Q^T Z$ is a vector of size m

Q comes from the QR decomposition of the matrix B

Z is the right hand side of the linear system BX=Z

m is the number of Doris measurements of the whole data set (spanning two days)

p is the number of TEC values estimated on the two working grids

After normalization, the quality index is given by :

$$Quality\_index = \sqrt{\frac{S}{m+k}}\, cst \tag{2}$$

where k is the number of pseudo measurements introduced to insure TEC continuity

cst is a constant fixed in the processing parameters

Standard deviation of TEC values at working grid points

$$Std = \sqrt{\frac{\sum_{i=1}^{p} X_i^2}{p}} \quad (3)$$

where X_i is the TEC value at working grid point i

p is the number of points of the two working grids

Covariance matrix of the system RX = T

$$Mat\_Cov = R^{-1}R^{-T} \quad (4)$$

where the expression R^{-T} stands for the transpose of the matrix R^{-1}

Covariance at an output grid point

Covariance at an output grid point is calculated by the following equation:

$$Cov = \left(\sum_{j \in K} \alpha_j \sum_{k \in K} \alpha_k Mat\_Cov(j,k) \right)^{1/2} \quad (5)$$

where α_k is the interpolation coefficient associated to grid point k, used in the interpolation of the points surrounding the output grid point

K is the set of indexes of the working grid points involved in the interpolation

ALGORITHM SPECIFICATION

Warning

- The computation of the first longitude for the working grids and for the output grids
- The computation of the number of Doris measurements used for the estimation

are considered as part of "data management and control algorithms". They are specified in the document RD1.

Input data

- Number of points of the two working grids : Nb (/)
- Number of points of the descending grid : Nb_desc (/)

- Number of Doris measurements used for the estimation : Nb_mes_estim (/)
- TEC values at working grid points : X[0:Nb-1] (0.1 TECU)
- Matrix with continuity constraints
  : R_tot[0:Nb*(Nb+1)/2 - 1] (m /s / 0.1 TECU)
- Quality index of the LS method : S_tot (m^2 / s^2)
- Number of pseudo measurements introduced for continuity : Nb_pseudo_mes (/)

- Degree of interpolation versus latitude : Int_deg_lat (/)
- Degree of interpolation versus longitude : Int_deg_lon (/)
- Offset on the limits of the working grid in longitude : Offset_lon_wk_grid (degrees)
- Weighting constant for the quality index of the LS method : Cst_weight_norm_S (/)
- Features of the output grid of kind y (y = asc and desc) :
  - First latitude of the output grid : First_lat_out_y (degrees)
  - Number of latitude of the output grid : Nb_lat_out_y (/)
  - Latitude step of the output grid : Step_lat_out_y (degrees)
  - First longitude of the output grid : First_lon_out_y (degrees)
  - Number of longitude of the output grid : Nb_lon_out_y (/)
  - Longitude step of the output grid : Step_lon_out_y (degrees)
- Features of the working grid of kind y (y = asc and desc) :
  - Latitude min of the working grid : First_lat_wk_y (degrees)
  - Number of latitude of the working grid : Nb_lat_wk_y (/)
  - Latitude step of the working grid : Step_lat_wk_y (degrees)
  - Longitude min of the working grid : First_lon_wk_y (degrees)
  - Number of longitude of the working grid : Nb_lon_wk_y (/)
  - Longitude step of the working grid : Step_lon_wk_y (degrees)
- Features of the grid of Dip values :
  - Number of grid points in the longitude axis : Nb_lon_dip (/)
  - Number of grid points in the latitude axis : Nb_lat_dip (/)
  - Grid step in the longitude axis : Lon_step_dip (degrees)
  - Grid step in the latitude axis : Lat_step_dip (degrees)
  - First tabulated latitude value : Lon_first_dip (degrees)
  - First tabulated longitude value : Lat_first_dip (degrees)
- Table of Dip values : : Tab_dip[0:Nb_lon_dip-1][0:Nb_lat_dip-1] (radians)

Output data

- Normalized quality index of the LS method : Norm_S (m^2 / s^2)
- Standard deviation of TEC values at working grid points : Std_TEC (0.1 TECU)
- Covariance matrix of the system : Mat_cov [0:Nb- 1][0:Nb-1](same unit as $(1/R\_tot)^2$)
- Covariance on the ascending output grid : Cov_out_grid_asc[0:Nb_lat_out_asc-1][0:Nb_lon_out_asc-1] (same unit as 1/R_tot)
- Covariance on the descending output grid : Cov_out_grid_desc[0:Nb_lat_out_desc-1][0:Nb_lon_out_desc-1] (same unit as 1/R_tot)
- Output from the NAG routine F07UJF : Info (/)

Processing

Quality index of the LS method

The normalized quality index is computed using equation (2) from the definition section :

$$Norm\_S = Cst\_weight\_norm\_S * [\ S\_tot / (Nb\_mes\_estim + Nb\_pseudo\_mes)\ ]^{1/2}$$

Standard deviation of TEC values at working grid points

Standard deviation of TEC values is computed using equation (3) from the definition section, with TEC values on the working grid (X) :

$$Std\_TEC = \left(\frac{\sum_{i=0}^{Nb-1} X(i)^2}{Nb} \right)^{1/2} \qquad (2)$$

Covariance matrix

The covariance matrix is computed using equation (4) from the definition section with the following steps :

- To perform the inversion of R_tot

  The inverse matrix of R_tot is computed using routine F07UJF of the NAG Fortran library (RD8).

  This function is called with the following arguments:

UPLO	= ‘L’	[input]
DIAG	= ‘N’	[input]
N	= Nb	[input]
AP	= R_tot (triangular matrix stored in one vector)	[input/output]
INFO		[output]

LENGTH_1 = 1 (length of the string UPLO) [input]
LENGTH_2 = 1 (length of the string DIAG) [input]

The output of the routine R_tot is an array of one dimension, storing the lower triangular matrix $(R\_tot^{-1})^T$ column by column

The output INFO has the following values :

- INFO = 0 for a normal ending
- INFO = -i when the ith argument of the routine has an illegal value (this case can not occur)
- INFO = i when the ith diagonal element of R_tot is zero, the matrix R_tot is then singular

If (INFO > 0) then the processing of the algorithm is stopped and the following outputs are set to default values :

- Covariance matrix of the system : Mat_cov [0:Nb- 1][0:Nb-1]
- Covariance on the ascending output grid
  : Cov_out_grid_asc[0:Nb_lat_out_asc-1][0:Nb_lon_out_asc-1]
- Covariance on the descending output grid
  : Cov_out_grid_desc[0:Nb_lat_out_desc-1][0:Nb_lon_out_desc-1]

- To store the matrix $(R\_tot^{-1})^T$ in a two dimension array named A and the matrix R_tot^{-1} in a two dimension array named B. These conversions are needed for the use of the routine from the Fortran library as the inputs for the matrixes are arrays of two dimensions.
  - To initialize the arrays A and B to zero
  - To form the array A

    For i = 0, Nb-1

      For j = 0, i (the matrix A is lower triangular)

    $$k = i + (2*Nb – j – 1) * j / 2 \tag{3}$$

    $$A(i,j) = R\_tot(k) \tag{4}$$

  - To form the array B : B is the transpose of matrix A

    For i = 0, Nb-1

      For j = 0,Nb-1

    $$B(i,j) = A(j,i) \tag{5}$$

- To compute the matrix product Mat_cov = B*A :

  The matrix product is computed using routine F06YFF of the NAG Fortran library (RD8).

  This function is called with the following arguments:

  SIDE = 'R' [input]
  UPLO = 'L' [input]
  TRANSA = 'N' [input]
  DIAG = 'N' [input]
  M = Nb [input]

N	= Nb	[input]
ALPHA	= 1.0	[input]
A	= A	[input]
LDA	= Nb (the value of the first dimension of A as declared in the program)	[input]
B	= B	[input/output]
LDB	= Nb (the value of the first dimension of B as declared in the program)	[input]
LENGTH_1	= 1 (length of the string SIDE)	[input]
LENGTH_2	= 1 (length of the string UPLO)	[input]
LENGTH_3	= 1 (length of the string TRANSA)	[input]
LENGTH_4	= 1 (length of the string DIAG)	[input]

The output of the routine is stored in B

- To store the result in the covariance matrix :

  Mat_cov = B (6)

Covariance on the output grid

For each point of the ascending output grid and of the descending output grid, covariance of TEC is computed. The processing is specified for a grid of kind y with y = asc, desc.

- To compute position of the output grid point (i,j)

  Latitude = First_lat_out_y + i * Step_lat_out_y with i∈[0,Nb_lat_out_y –1] (7)
  Longitude = First_lon_out_y + j * Step_lon_out_y with j∈[0,Nb_lon_out_y -1] (8)

- To convert geographic latitude of output grid point into geomagnetic latitude (Lat_mag) using "GEN_MEC_CON_05 - Conversion between geographic and geomagnetic latitude" with the following inputs:

  Latitude (degrees), Longitude (degrees) and Dip data

  If the output flag Flag_grid is "invalid" then the value of the covariance at the output grid point (i,j) {Cov_out_grid_y(i,j)} is set to a default value.
- To compute interpolation coefficients of the TEC value at point (i,j)

  To convert the geomagnetic latitude (Lat_mag) into degrees

  To compute interpolation coefficients on the working grid of kind y, using mechanism GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid" with the following inputs :

  Int_deg_lat, Int_deg_lon, Lat_mag, Longitude, Offset_lon_wk_grid, First_lat_wk_y, Step_lat_wk_y, Nb_lat_wk_y, First_lon_wk_y, Step_lon_wk_y, Nb_lon_wk_y.

  Results are indexes minimum and maximum (Min, Max) of grid points used in the interpolation, coefficients of interpolation (Coeff_out(k), k∈ [Min, Max]) and an output flag (Flag_interp).

  If the output flag Flag_interp is "invalid" then the value of the covariance at the output grid point (i,j) {Cov_out_grid_y(i,j)} is set to a default value.

- To compute covariance at grid point (i,j) (Cov_out_grid_y), using equation (5) and the covariance matrix Mat_cov :

- If the grid is descending then

$$\text{Cov\_out\_grid\_desc}(i,j) = \left(\sum_{k=\text{Min}}^{\text{Max}} \text{Coeff\_out}(k) \sum_{q=\text{Min}}^{\text{Max}} \text{Coeff\_out}(q)\ \text{Mat\_cov}(k,q) \right)^{1/2} \tag{9}$$

- Else the grid is ascending then

$$\text{Coeff\_out}(k+\text{Nb\_desc}) = \text{Coeff\_out}(k) \text{ for } k = \text{Min,Max} \tag{10}$$

$$\text{Min} = \text{Min} + \text{Nb\_desc} \tag{11}$$

$$\text{Max} = \text{Max} + \text{Nb\_desc} \tag{12}$$

$$\text{Cov\_out\_grid\_asc}(i,j) = \left(\sum_{k=\text{Min}}^{\text{Max}} \text{Coeff\_out}(k) \sum_{q=\text{Min}}^{\text{Max}} \text{Coeff\_out}(q)\ \text{Mat\_cov}(k,q) \right)^{1/2} \tag{13}$$

ACCURACY

N/A

COMMENTS

The TECU is the TEC Unit and 1 TECU = 10^{16} electrons/m^2

REFERENCES

Trajectoires Spatiales, O. Zarrouati, 1987, CNES (p. 368-400)

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LOS_ION_QUA_05 - To compute the Doris residuals after the TEC estimation

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT	

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Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To compute the residual on the Doris measurement after the TEC estimation.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data:
  - Doris data
- Computed data :
  - From "LOS_ION_GTY_02 - To compute the position of the subionospheric point"
    - Latitude of the subionospheric point at the beginning of the counting period
    - Latitude of the subionospheric point at the end of the counting period
  - From "LOS_ION_GTY_03 - To calculate the modified longitude of the subionospheric point"
    - Longitude of the subionospheric point at the beginning of the counting period
    - Longitude of the subionospheric point at the end of the counting period
  - From "LOS_ION_GTY_04 - To calculate the conversion coefficient between vertical TEC and slant TEC"
    - Conversion coefficient between vertical TEC and slant TEC at the beginning of the counting period
    - Conversion coefficient between vertical TEC and slant TEC at the end of the counting period
  - From "LOS_ION_TEC_01 - LOS_ION_TEC_01 - To establish the linear system for the computation of TEC on the grid in geomagnetic latitude"
    - Flag on the measurement used for the TEC estimation
  - From "LOS_ION_TEC_03 - To compute TEC values on the grid in geomagnetic latitude "
    - TEC values at working grid points for ascending and descending grids
- Dynamic auxiliary data: none
- Static auxiliary data:
  - Processing parameters
    - Features of the working grids
    - Number of points of the two working grid
    - Degree of interpolation versus latitude

- * Degree of interpolation versus longitude
  * Offset on the limits of the working grid in longitude
- Dip data

Output data

- Residual on the Doris measurement

Mathematical statement

The residual on the Doris measurement is computed by the difference between the real measurement and the Doris measurement computed after the TEC estimation :

$$\text{Res} = \text{Dor\_mes} - \text{Mod\_mes} \quad (1)$$

Where Mod_mes is calculated by the following equation which gives the Doris measurement from the TEC values :

$$\text{Mod\_mes} = c_1 * [k_1\,\text{TEC1} - k_2\,\text{TEC2}] \quad (2)$$

where $dmes(n)$ is the value of Doris measurement n

c_1 is a parameter of the processing to link Doris measurement and TEC value

k_1 is the conversion coefficient between vertical TEC and slant TEC of subionospheric point n, at the beginning of the counting period

$TEC1(n)$ is the TEC value of subionospheric point n, at the beginning of the counting period

k_2 is the conversion coefficient between vertical TEC and slant TEC of subionospheric point n, at the end of the counting period

$TEC2(n)$ is the TEC value of subionospheric point n, at the end of the counting period

ALGORITHM SPECIFICATION

The processing is performed for each Doris measurement of the whole data set.

Warning

- The computation of Doris measurements from Doris level 1.0 parameters
- The computation of the type of the measurement
- The computation of the first longitude for the working grids
- The computation of the parameter to link Doris measurements and the TEC values

are considered as part of "data management and control algorithms". They are specified in the document RD1.

Input data

- Number of points of the two working grids : Nb (/)
- Number of points of the descending working grid : Nb_desc (/)
- TEC values at working grid points : X[0:Nb-1] (0.1 TECU)
- Degree of interpolation versus latitude : Int_deg_lat (/)
- Degree of interpolation versus longitude : Int_deg_lon (/)
- Offset on the limits of the working grid in longitude : Offset_lon_wk_grid (degrees)
- Parameter to link Doris measurement and the TEC values : Par_dor_TEC (m /s / 0.1 TECU)

- Features of the working grid of kind y (y = asc or desc) :
  - Latitude min of the working grid : First_lat_wk_y (degrees)
  - Number of latitude of the working grid : Nb_lat_wk_y (/)
  - Latitude step of the working grid : Step_lat_wk_y (degrees)
  - Longitude min of the working grid : First_lon_wk_y (degrees)
  - Number of longitude of the working grid : Nb_lon_wk_y (/)
  - Longitude step of the working grid : Step_lon_wk_y (degrees)

- Value of Doris measurement : Dor_mes (m/s)
- Latitude of subionospheric point at the beginning of the counting period : Lat_sub_bgn (degrees)
- Latitude of subionospheric point at the end of the counting period : Lat_sub_end (degrees)
- Longitude of subionospheric point at the beginning of the counting period : Lon_sub_bgn (degrees)
- Longitude of subionospheric point at the end of the counting period : Lon_sub_end (degrees)
- Conversion coefficient between vertical TEC and slant TEC at the beginning of the counting period : K_bgn (/)
- Conversion coefficient between vertical TEC and slant TEC at the end of the counting period : K_end (/)
- Flag on the measurement used for the TEC estimation : Estim_val_flag [(1)]
- Type of the measurement : Type (asc or desc)

- Features of the grid of Dip values :

[(1)] 2 states: "valid" or "invalid"

- Number of grid points in the longitude axis : Nb_lon_dip (/)
- Number of grid points in the latitude axis : Nb_lat_dip (/)
- Grid step in the longitude axis : Lon_step_dip (degrees)
- Grid step in the latitude axis : Lat_step_dip (degrees)
- First tabulated latitude value : Lon_first_dip (degrees)
- First tabulated longitude value : Lat_first_dip (degrees)

Table of Dip values : : Tab_dip[0:Nb_lon_dip-1][0:Nb_lat_dip-1] (radians)

Output data

- Residual on the Doris measurement after the TEC estimation : Res (m/s)

Processing

The following processing is performed for the measurement :

- If Estim_val_flag is "invalid" then the following processing is not performed and the residual Res is set to a default value.
- To compute TEC value at the subionospheric point at the beginning of the counting period (TEC_sub_bgn) by interpolation on the working grid of kind Type.
  - To convert geographic latitude of subionospheric point at beginning of counting period into geomagnetic latitude (Lat_sub_bgn_mag) using "GEN_MEC_CON_05 - Conversion between geographic and geomagnetic latitude" with the following inputs :

    Lat_sub_bgn, Lon_sub_bgn
  - To compute interpolation coefficients on the working grid of kind Type, using mechanism "GEN_MEC_INT_09 - Computation of the coefficients of a polynomial interpolation on a two dimension grid" with the following inputs :

    The input Lat_sub_bgn_mag (in radians) must be converted in degrees.

    Int_deg_lat, Int_deg_lon, Lat_sub_bgn_mag, Lon_sub_bgn, Offset_lon_wk_grid, First_lat_wk_Type, Step_lat_wk_Type, Nb_lat_wk_Type, First_lon_wk_Type, Step_lon_wk_Type, Nb_lon_wk_Type

    Results are indexes minimum and maximum (Min, Max) of grid points used in the interpolation, coefficients of interpolation (Coeff_sub_bgn(k), $k \in [\text{Min}, \text{Max}]$) and an output flag (Flag_interp_bgn).
  - If the measurement is descending (Type = desc) then :

$$\text{TEC\_sub\_bgn} = \sum_{k=\text{Min}}^{\text{Max}} \text{Coeff\_sub\_bgn}(k) * X(k) \tag{1}$$

  - Else the measurement is ascending (Type = asc) then :

    For the ascending TEC, special processing must be performed using a translation of indexes k on X because ascending values of TEC are stored in X(k) $k \in [\text{Nb\_desc}, \text{Nb} - 1]$. Thus the TEC value is computed by:

$$\text{TEC\_sub\_bgn} = \sum_{k=\text{Min}}^{\text{Max}} \text{Coeff\_sub\_bgn}(k) * X(k + \text{Nb\_desc}) \tag{2}$$

- The same processing is applied for the subionospheric point at the end of the counting period and the TEC value at the subionospheric point at the end of the counting period is given by :
  - If the measurement is descending then :

$$TEC\_sub\_end = \sum_{k=Min}^{Max} Coeff\_sub\_end(k) * X(k) \quad (3)$$

  - Else the measurement is ascending :

$$TEC\_sub\_end = \sum_{k=Min}^{Max} Coeff\_sub\_bgn(k) * X(k + Nb\_desc) \quad (4)$$

- To recompose the modeled measurement (Mod_mes) :

Mod_mes = Par_dor_TEC * [K_bgn * TEC_sub_bgn – K_end * TEC_sub_end] (5)

- To compute the residual of Doris measurement :

Res = Dor_mes – Mod_mes (6)

ACCURACY

N/A

COMMENTS

The TECU is the TEC Unit and 1 TECU = 10^{16} electrons/m^2

REFERENCES

None

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LOS_ION_QUA_06 - To perform statistics on the Doris measurements after the TEC estimation

DEFINITION, ACCURACY AND SPECIFICATION

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Algorithm change record	Creation	Date	Issue:	Update:
	CCM			

HERITAGE

TOPEX-POSEIDON

FUNCTION

To compute statistics on the residuals of the Doris measurement after the TEC estimation.

APPLICABILITY

JASON-1
ENVISAT

ALGORITHM DEFINITION

Input data

- Product data:
  - Doris data spanning two days
- Computed data :
  - From " LOS_ION_QUA_05 - To compute the Doris residuals after the TEC estimation"
    - Residual on the Doris measurement after the TEC estimation
  - From "LOS_ION_TEC_01 - LOS_ION_TEC_01 - To establish the linear system for the computation of TEC on the grid in geomagnetic latitude"
    - Flag on the measurement used for the TEC estimation
- Dynamic auxiliary data:
  - Doris beacon data
- Static auxiliary data: none
- Processing parameters :
  - Number of days covered by the data

Output data

- Statistics for the residuals of Doris measurements

Mathematical statement

Mean and standard deviation for the residuals of Doris measurements are computed :

- for each visibility segment of the whole data set spanning two days, taking into account all the treatment units
- for each beacon over the day D (the day the TEC values are computed). It is performed for each treatment unit and also mixing all the treatment units, for the ascending, descending measurements and globally.
- for all the measurements over the day D. It is performed for each treatment unit and also mixing all the treatment units, for the ascending, descending measurements and globally.

ALGORITHM SPECIFICATION

Warning

- The computation of the number of treatment units
- The computation of the number of visibility segments
- The computation of the number of measurements for each visibility segment
- The computation of the identity number of the beacons
- The computation of the type of the pass for each measurement
- The computation of the time-tag for each measurement
- The computation of the day of the first measurement

are considered as part of "data management and control algorithms". They are specified in the document RD1.

Input data

- Number of treatment units : Nb_UT (/)
- Number of visibility segments : Nb_visi_seg [0:Nb_UT-1] (/)
- Identity number of the beacon for each visibility segment : Id_beac_visi [0:Nb_UT-1] [0:Nb_visi_seg-1] (/)
- Number of measurements for each visibility segment : Nb_mes [0:Nb_UT-1] [0:Nb_visi_seg-1] (/)
- For each measurement:
  - Residual on the Doris measurement after the TEC estimation : Res [0:Nb_UT-1] [0:Nb_visi_seg-1] [0:Nb_mes-1] (m/s)
  - Type of the measurement : Type[0:Nb_UT-1] [0:Nb_visi_seg-1] [0:Nb_mes-1] (asc or desc)
  - Time-tag of the Doris measurement : Time_tag_dor_mes[0:Nb_UT-1] [0:Nb_visi_seg-1][0:Nb_mes-1](s)
  - Flag on the measurement used for the TEC estimation : Estim_val_flag [0:Nb_UT-1] [0:Nb_visi_seg-1][0:Nb_mes-1] (1)
- Number of beacons for the day of the TEC estimation : Nb_beacon_D_sec (/)
- Identity number of the beacons for the day of the TEC estimation : Id_beacon_D_sec [0:Nb_beacon_D_sec-1]
- Day of the TEC estimation : Day_sec (/) (2)

(1) 2 states: "valid" or "invalid"

(2) in number of days elapsed since the 01/01/1950 at 0h

Output data

- Statistics on each visibility segment
  - Mean and standard deviation for the residuals of Doris measurements : Mean_res_visi [0:Nb_UT-1] [0:Nb_visi_seg-1], Std_res_visi [0:Nb_UT-1] [0:Nb_visi_seg-1] (m/s)
- Statistics on the residuals of the Doris measurements collected by the beacons, for the day of estimation :
  - Global
    - ∗ Mean and standard deviation for the residuals of Doris measurements : Mean_res_beac_glob [0:Nb_beacon_D_sec-1], Std_res_beac_glob [0:Nb_beacon_D_sec-1] (m/s)
  - Descending
    - ∗ Mean and standard deviation for the residuals of Doris measurements : Mean_res_beac_desc [0:Nb_beacon_D_sec-1], Std_res_beac_desc [0:Nb_beacon_D_sec-1] (m/s)
  - Ascending

Mean and standard deviation for the residuals of Doris measurements : Mean_res_beac_asc [0:Nb_beacon_D_sec-1], Std_res_beac_asc [0:Nb_beacon_D_sec-1] (m/s)

- Statistics on the residuals of the Doris measurements collected by the beacons, for the day of estimation, for each treatment unit :
  - Global
    - ∗ Mean and standard deviation for the residuals of Doris measurements :

      Mean_res_beac_glob [0:Nb_UT-1] [0:Nb_beacon_D_sec-1]

      Std_res_beac_glob [0:Nb_UT-1] [0:Nb_beacon_D_sec-1] (m/s)
  - Descending
    - ∗ Mean and standard deviation for the residuals of Doris measurements :

      Mean_res_beac_desc [0:Nb_UT-1] [0:Nb_beacon_D_sec-1]

      Std_res_beac_desc [0:Nb_UT-1] [0:Nb_beacon_D_sec-1] (m/s)
  - Ascending
    - ∗ Mean and standard deviation for the residuals of Doris measurements :

      Mean_res_beac_asc [0:Nb_UT-1] [0:Nb_beacon_D_sec-1]

      Std_res_beac_asc [0:Nb_UT-1] [0:Nb_beacon_D_sec-1] (m/s)

- Statistics on the residuals of the Doris measurements of the day of estimation
  - Global
    - ∗ Mean and standard deviation for the residuals of Doris measurements : Mean_res_glob, Std_res_glob (m/s)
  - Descending
    - ∗ Mean and standard deviation for the residuals of Doris measurements : Mean_res_desc, Std_res_desc (m/s)
  - Ascending

* Mean and standard deviation for the residuals of Doris measurements
  : Mean_res_asc, Std_res_asc (m/s)

- Statistics on the residuals of the Doris measurements of the day of estimation, for each treatment unit
  - Global
    * Mean and standard deviation for the residuals of Doris measurements
      : Mean_res_glob [0:Nb_UT-1], Std_res_glob [0:Nb_UT-1] (m/s)
  - Descending
    * Mean and standard deviation for the residuals of Doris measurements
      : Mean_res_desc [0:Nb_UT-1], Std_res_desc [0:Nb_UT-1] (m/s)
  - Ascending
    * Mean and standard deviation for the residuals of Doris measurements
      : Mean_res_asc [0:Nb_UT-1], Std_res_asc [0:Nb_UT-1] (m/s)

Processing

The following algorithm is performed :

- For each valid visibility segment
- For all the measurements of the day the TEC estimation is performed
- For the measurements of kind Type, Type = asc and desc and of the day the estimation is performed
- For the measurements of the day the estimation is performed and associated to the beacon i
- For the measurements of kind Type, Type = asc and desc and of the day the estimation is performed, which are associated to the beacon i

- To compute the statistics for each visibility segment :

  For m = 0, Nb_UT-1

  For i = 0, Nb_visi_seg(m)-1

  - To select the valid measurements of the visibility segment :

    The N selected measurements Res_sel(k) are the values Res (m) (i) (j) with j = 0, Nb_mes(m)(i)-1 such that Estim_val_flag (m) (i) (j) is “valid”

  - To compute the mean and standard deviation for the visibility segment :

    Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

    Number of points : N

    Point values : Res_sel [0:N-1]

    The outputs are the following ones :

    Mean : Mean_res_visi (m) (i)

    Standard deviation : Std_res_visi (m) (i)

    Minimum value : unused

    Maximum value : unused

- The following processing is performed for each treatment unit and then taking into account all the treatment units :

  To compute the statistics on the Doris measurements of the day of estimation :

  - To select the visibility segments belonging to the day of estimation (Day_sec) :

    For m = 0, Nb_UT-1

    For i = 0, Nb_visi_seg(m)-1

    If (INT(Time_tag_dor_mes (m) (i) (0) / 86400) = Day_sec) then

    The N(m) selected measurements Res_day(k) are the values Res (m) (i) (j) with j = 0, Nb_mes(m)(i)-1 such that Estim_val_flag (m) (i) (j) is “valid”

    If (Type (m) (i) (j) is asc and Estim_val_flag (m) (i) (j) is “valid”) then

    Res_day_asc (k) = Res (m) (i) (j)

    N_asc(m) is the number of selected measurements for treatment unit m

    If (Type (m) (i) (j) is desc and Estim_val_flag (m) (i) (j) is “valid”) then

    Res_day_desc (k) = Res (m) (i) (j)

    N_desc(m) is the number of selected measurements for treatment unit m

  - To compute the mean and standard deviation for the selected measurements by treament units :

    For m = 0, Nb_UT-1

    Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

    Number of points : N(m)

    Point values : Res_day [0:N(m)-1]

    The outputs are the following ones :

    Mean : Mean_res_glob(m)

    Standard deviation : Std_res_glob(m)

    Minimum value : unused

    Maximum value : unused

  - To compute the mean and standard deviation for the selected measurements, depending on their type, by treatment unit :

    For m = 0, Nb_UT-1

    * For the ascending measurements :

      Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

      Number of points : N_asc(m)

      Point values : Res_day_asc [0:N_asc(m)-1]

      The outputs are the following ones :

      Mean : Mean_res_asc(m)

Standard deviation : Std_res_asc(m)

Minimum value : unused

Maximum value : unused

* For the descending measurements :

  Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

  Number of points : N_desc(m)

  Point values : Res_day_desc [0:N_desc(m)-1]

  The outputs are the following ones :

  Mean : Mean_res_desc(m)

  Standard deviation : Std_res_desc(m)

  Minimum value : unused

  Maximum value : unused

– To compute the mean and standard deviation for the selected measurements, mixing all the treatment units :

  Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

  Number of points : N ($N = \Sigma N(m)$, m = 0,Nb_UT-1)

  Point values : Res_day [0:N-1]

  The outputs are the following ones :

  Mean : Mean_res_glob

  Standard deviation : Std_res_glob

  Minimum value : unused

  Maximum value : unused

– To compute the mean and standard deviation for the selected measurements, depending on their type and mixing all the treatment units :

* For the ascending measurements :

  Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

  Number of points : N_asc (N_asc = Σ N_asc(m), m = 0,Nb_UT-1)

  Point values : Res_day_asc [0:N_asc-1]

  The outputs are the following ones :

  Mean : Mean_res_asc

  Standard deviation : Std_res_asc

  Minimum value : unused

  Maximum value : unused

* For the descending measurements :

  Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

  Number of points : N_desc (N_desc = Σ N_desc(m), m = 0,Nb_UT-1)

Point values : Res_day_desc [0:N_desc-1]

The outputs are the following ones :

Mean : Mean_res_desc

Standard deviation : Std_res_desc

Minimum value : unused

Maximum value : unused

- The following processing is performed for each treatment unit and then taking into account all the treatment units :

  To compute the statistics on the Doris measurements of the day of estimation, collected by each beacon

  For n = 0, Nb_beacon_D_sec-1 (to perform selection and statistics for each beacon)

  - To select the measurements of the day of estimation, for the beacon n

    For m = 0, Nb_UT-1

    For i = 0, Nb_visi_seg(m)-1

    If (INT(Time_tag_dor_mes (m)(i) (0) / 86400) = Day_sec)

    and (Id_beac_visi (m) (i) = Id_beacon_D_sec (n)) then

    The Nb(m) selected measurements Res(k) are the values Res (m) (i) (j) with j = 0, Nb_mes (m) (i)-1 such that Estim_val_flag (m) (i) (j) is “valid”

    If (Type (m) (i) (j) is asc and Estim_val_flag (m) (i) (j) is “valid”) then

    Res_beac_asc (k) = Res (m) (i) (j)

    N_asc(m) is the number of selected measurements for treatment unit m

    If (Type (m) (i) (j) is desc and Estim_val_flag (m) (i) (j) is “valid”) then

    Res_beac_desc (k) = Res (m) (i) (j)

    N_desc(m) is the number of selected measurements for treatment unit m

  - To compute the mean and standard deviation for the selected measurements by treatment units :

    For m = 0, Nb_UT-1

    Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

    Number of points : Nb(m)

    Point values : Res [0:Nb(m)-1]

    The outputs are the following ones :

    Mean : Mean_res_beac_glob (m) (n)

    Standard deviation : Std_res_beac_glob(m) (n)

    Minimum value : unused

    Maximum value : unused

  - To compute the mean and standard deviation for the selected measurements, depending on their type, by teatment units :

For m = 0, Nb_UT-1

* For the ascending measurements :

  Using mechanism "GEN_MEC_COM_01 - Arithmetic averaging" with the following inputs :

Number of points	: N_asc(m)
Point values	: Res_beac_asc [0:N_asc(m)-1]

  The outputs are the following ones :

Mean	: Mean_res_beac_asc (m) (n)
Standard deviation	: Std_res_beac_asc (m) (n)
Minimum value	: unused
Maximum value	: unused

* For the descending measurements :

  Using mechanism "GEN_MEC_COM_01 - Arithmetic averaging" with the following inputs :

Number of points	: N_desc(m)
Point values	: Res_beac_desc [0:N_desc(m)-1]

  The outputs are the following ones :

Mean	: Mean_res_beac_desc (m) (n)
Standard deviation	: Std_res_beac_desc (m) (n)
Minimum value	: unused
Maximum value	: unused

- To compute the mean and standard deviation for the selected measurements, mixing all the treatment units :

  Using mechanism "GEN_MEC_COM_01 - Arithmetic averaging" with the following inputs :

Number of points	: Nb (Nb = Σ Nb(m), m = 0,Nb_UT-1)
Point values	: Res [0:Nb-1]

  The outputs are the following ones :

Mean	: Mean_res_beac_glob(n)
Standard deviation	: Std_res_beac_glob(n)
Minimum value	: unused
Maximum value	: unused

- To compute the mean and standard deviation for the selected measurements, depending on their type and mixing all the treatment units :

  * For the ascending measurements :

    Using mechanism "GEN_MEC_COM_01 - Arithmetic averaging" with the following inputs :

Number of points	: N_asc (N_asc = Σ N_asc(m), m = 0,Nb_UT-1)
Point values	: Res_beac_asc [0:N_asc-1]

    The outputs are the following ones :

Mean	: Mean_res_beac_asc(n)

Standard deviation : Std_res_beac_asc(n)

Minimum value : unused

Maximum value : unused

* For the descending measurements :

  Using mechanism “GEN_MEC_COM_01 - Arithmetic averaging” with the following inputs :

  Number of points : N_desc (N_desc = Σ N_desc(m), m = 0,Nb_UT-1)

  Point values : Res_beac_desc [0:N_desc-1]

  The outputs are the following ones :

  Mean : Mean_res_beac_desc(n)

  Standard deviation : Std_res_beac_desc(n)

  Minimum value : unused

  Maximum value : unused

ACCURACY

N/A

COMMENTS

The TECU is the TEC Unit and 1 TECU = 10^{16} electrons/m^2

REFERENCES

None

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